Idaho National Engineering and Environmental Laboratory

INEEL/EXT-02-00589
Volume 3
Revision 2.2
October 2003

# SCDAP/RELAP5-3D© CODE MANUAL

## VOLUME 3: USER'S GUIDE AND INPUT MANUAL

*SCDAP/RELAP5-3D© Code Development Team*

BECHTEL BWXT IDAHO, LLC

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Prepared Under DOE Contract No. DE-AC07-99ID13737

# CONTENTS

# FIGURES

# ABSTRACT

The SCDAP/RELAP5-3D© code has been developed for best-estimate transient simulation of light water reactor coolant systems during a severe accident. The code models the coupled behavior of the reactor coolant system and reactor core during severe accidents as well as large and small break loss-of-coolant accidents, operational transients such as anticipated transient without SCRAM, loss of offsite power, loss of feedwater, and loss of flow. The coolant system behavior is calculated using a two-phase model allowing for unequal temperatures and velocities of the two phases of the fluid, and the flow of fluid through porous debris and around blockages caused by reactor core damage. The reactor core behavior is calculated using models for the ballooning and oxidation of fuel rods, the meltdown of fuel rods and control rods, fission product release, and debris formation. The code also calculates the heatup and structural damage of the lower head of the reactor vessel resulting from the slumping of reactor core material. A generic modeling approach is used that permits as much of a particular system to be modeled as necessary. Control system and secondary system components are included to permit modeling of plant controls, turbines, condensers, and secondary feedwater conditioning systems.

This volume provides guidelines to code users based upon lessons learned during the developmental assessment process. A description of problem control and the installation process is included. Appendix A contains the description of SCDAP input requirements for SCDAP/RELAP5-3D©.

# EXECUTIVE SUMMARY

The specific features of SCDAP/RELAP5-3D© are described in this five volume set of manuals covering the theory, use, and assessment of the code for severe accident applications.

The SCDAP/RELAP5-3D© computer code is designed to calculate for severe accident situations the overall reactor coolant system (RCS) thermal-hydraulic response, core damage progression, and reactor vessel heatup and damage. The SCDAP/RELAP5-3D© code evolved from the RELAP5 and SCDAP/RELAP5 codes developed at the Idaho National Engineering & Environmental Laboratory (INEEL) under sponsorship by the U.S. Nuclear Regulatory Commission (US NRC). Development of the RELAP5 code series began at the INEEL in 1975, while SCDAP development was initiated in the early 1970's with an active linkage to RELAP5 in 1979. The SCDAP/RELAP5-3D© code maintained all of the capabilities and validation history of the predecessor codes, plus the added capabilities sponsored by the DOE.

The RELAP5 code is based on a two-fluid model allowing for unequal temperatures and velocities of the fluids and the flow of fluid through porous debris and around blockages caused by reactor core damage. The models in SCDAP calculate the progression of damage to the reactor core. These models calculate the heatup, oxidation and meltdown of fuel rods and control rods, the ballooning and rupture of fuel rod cladding, the release of fission products from fuel rods, and the disintegration of fuel rods into porous debris and molten material. The SCDAP models also calculate the heatup and structural damage of the reactor vessel lower head resulting from the slumping to the lower head of reactor core material with internal heat generation. SCDAP/RELAP5-3D© can be used in analyses of fission product transport and deposition behavior and containment phenomena by linking it to the detailed fission product code, VICTORIA[1] or CONTAIN[2], respectively.

The SCDAP/RELAP5-3D© code includes many generic component models from which general systems can be simulated. The component models include fuel rods, control rods, pumps, valves, pipes, reactor vessel, electrical fuel rod simulators, jet pumps, turbines, separators, accumulators, and control system components. In addition, special process models are included for effects such as form loss, flow at an abrupt area change, branching, choked flow, boron tracking, and noncondensable gas transport. The code also includes a model for reactor kinetics.

This volume, Volume 3, gives detailed descriptions of the input preparation and execution procedures. It also provides code installation procedures, as well as general guidelines on code applications.

1. N. E. Bixler, "VICTORIA2.0: A Mechanistic model for Radionuclide Behavior in a Nuclear Reactor Coolant System Under Severe Accident Conditions," NUREG/CR-6131, SAND93-2301, December 1998.
2. K. D. Bergeron et al., *User's Manual for CONTAIN 1.0, A Computer Code for Severe Nuclear Reactor Accident Containment Analysis*, NUREG/CR-4085, SAND84-1204, May 1985

# 1. INTRODUCTION

The SCDAP/RELAP5-3D© computer code is designed to calculate for severe accident situations the overall reactor coolant system (RCS) thermal-hydraulic response, reactor core and vessel damage progression, and, in combination with VICTORIA[1] fission product release and transport during severe accidents.

## 1.1 General Code Capabilities

The SCDAP/RELAP5-3D© code contains RELAP5 and SCDAP models. The RELAP5 models calculate the overall RCS thermal-hydraulics, control system interactions, reactor kinetics, and transport of noncondensable gases. A model is also included in RELAP5 to calculate flow losses in porous debris. Although previous versions of the code have included the analysis of fission product transport and deposition behavior using models derived from TRAP-MELT, this capability has been replaced through a data link to the detailed fission product code, VICTORIA. The SCDAP models calculate the heatup and damage progression in the core structures and the lower head of the reactor vessel. The calculations of damage progression include calculations of the meltdown of fuel rods and structures, the fragmentation of embrittled fuel rods, convective and radiative heat transfer in porous debris, the formation of a molten pool of core material, and the slumping of molten material to the lower head.

SCDAP/RELAP5-3D© is capable of modeling a wide range of system configurations from single pipes to different experimental facilities to full-scale reactor systems. The configurations can be modeled using an arbitrary number of fluid control volumes and connecting junctions, heat structures, core components, and system components. Flow areas, volumes, and flow resistances can vary with time through either user-control or models that describe the changes in geometry associated with damage in the core. System structures can be modeled with RELAP5 heat structures, SCDAP core components, or SCDAP debris models. The RELAP5 heat structures are one-dimensional models with slab, cylindrical, or spherical geometries. The SCDAP core components include representative light water reactor (LWR) fuel rods, silver-indium-cadmium (Ag-In-Cd) and $B_4C$ control rods and/or blades, electrically heated fuel rod simulators, and general structures. A two-dimensional, finite element heat conduction model based on the COUPLE[2] code may be used to calculate the heatup of the lower head of the reactor vessel and the slumped material supported by the lower head. This model takes into account the decay heat and internal energy of newly fallen or formed debris and then calculates the transport by conduction of this heat in the radial and axial directions to the wall structures and water surrounding the debris. The most important use of this model is to calculate the heatup of the vessel lower head and the timing of its failure in response to contact with material that has slumped from the core region. Other system components available to the user include pumps, valves, electric heaters, jet pumps, turbines, separators, and accumulators. Models to describe selected processes, such as reactor kinetics, control system response, and tracking noncondensable gases, can be invoked through user control.

The SCDAP/RELAP5-3D© code evolved from the RELAP5 and SCDAP/RELAP5 codes developed at the Idaho National Engineering & Environmental Laboratory (INEEL) under sponsorship by the U.S.

Nuclear Regulatory Commission (US NRC). Development of the RELAP5 code series began at the INEEL in 1975, while SCDAP development was initiated in the early 1970's with an active linkage to RELAP5 in 1979. Following the accident at Chernobyl, the U.S. Department of Energy (DOE) began a re-assessment of the safety of its test and production reactors, and chose RELAP5 and SCDAP/RELAP5 as the analytical tools for system safety analysis because of their wide spread acceptance and ease of application to such widely varying systems. Systematic safety analyses were performed for the N reactor at Hanford, the K and L reactors at Savannah River, the Advanced Test Reactor (ATR) at INEEL, the High Flux Isotope Reactor (HFIR) and Advanced Neutron Source (ANS) at Oak Ridge, and the High Flux Beam Reactor at Brookhaven. DOE also chose RELAP5 for the independent safety analysis of the New Production Reactor (NPR) before that program was cancelled.

The application of SCDAP/RELAP5 and RELAP5 to these widely varying reactor designs demanded new modeling capabilities, including non-light water reactor (LWR) materials and geometry. These widely varying demands were met by maintaining a single source with options that could be selected or deselected at compilation. In this fashion both NRC and DOE users could receive maximum benefit from the others development efforts. After the transmittal of SCDAP/RELAP5 MOD3.3 to the NRC, it became clear, however, that the efficiencies realized by the maintenance of a single source code for use by both NRC and DOE were being overcome by the extra effort required to accommodate sometimes conflicting goals and requirements. The codes were therefore “split” into two versions, SCDAP/RELAP5 MOD3.3 for the NRC and SCDAP/RELAP5-3D© for DOE. The SCDAP/RELAP5-3D© code maintained all of the capabilities and validation history of the predecessor codes, plus the added capabilities sponsored by the DOE.

SCDAP/RELAP5-3D© is the latest INEEL-developed code for analyzing transients and accidents in water-cooled nuclear power plants and related systems. The most prominent attribute that distinguishes this code from its predecessors is the fully integrated, multi-dimensional thermal-hydraulic and kinetic modeling capability. Although multi-dimensional capabilities in the RELAP models have been assessed, it should be noted that few of these assessment calculations have used SCDAP models.

## 1.2 Relationship to Other Software

SCDAP/RELAP5-3D© and RELAP5-3D© were developed in parallel and share a common configuration. Both codes share a common source deck. Separate codes are formed only prior to compilation, so changes made to the source deck are automatically reflected in both codes.

The development and application of the code is also related to several other software packages. Theoretical work associated with the development of PARAGRASS-VFP[3] has resulted in model improvements for fission product release. A data link to the VICTORIA code allows for the detailed treatment of phenomena such as fission product and aerosol transport, deposition, and resuspension. A link with PATRAN[4] and ABAQUS[5] provides the user with the means to calculate the details of lower head failure. Animated plant response displays are possible through links to the Nuclear Plant Analyzer (NPA)[6] display software, which gives the user an efficient way of analyzing the large amount of data generated. Detailed plant simulations from accident initiation through release of fission products to the atmosphere are made available through links to the CONTAIN[7] containment response and CRAC2[8] or MACCS[9] atmospheric dispersion consequence codes.

## 1.3 Quality Assurance

SCDAP/RELAP5-3D© is maintained under a strict code configuration system that provides a historical record of the changes made to the code. Changes are made using an update processor that allows separate identification of improvements made to each successive version of the code. Modifications and improvements to the coding are reviewed and checked as part of a formal quality program for software. In addition, the theory and implementation of code improvements are validated through assessment calculations that compare the code-predicted results to idealized test cases or experimental results.

## 1.4 Organization of the SCDAP/RELAP5-3D© Manuals

The specific features of SCDAP/RELAP5-3D© are described in a five-volume set of manuals covering the theory (Volume 2), user's guidelines and input manual (Volume 3), material properties (Volume 4), and assessment (Volume 5). Although Volume 1 describes (a) the overall code architecture, (b) interfaces between the RELAP5 and SCDAP models, and (c) any system models unique to SCDAP/RELAP5-3D©, the code user is referred to the companion set of six volumes which describe the RELAP5-3D© system thermal-hydraulics and associated models.

Volume 1 presents a description of SCDAP/RELAP5-3D©-specific thermal-hydraulic models (relative to RELAP5-3D©), and interfaces between the thermal-hydraulic models and damage progression models. Volume 2 contains detailed descriptions of the severe accident models and correlations. It provides the user with the underlying assumptions and simplifications used to generate and implement the basic equations into the code, so an intelligent assessment of the applicability and accuracy of the resulting calculation can be made. Volume 3 provides the user's guide and code input for the severe accident modeling. User guidelines are produced specifically for the severe accident code. The user should also refer to the RELAP5-3D© Code Manual Volume V: User Guidelines for a complete set of guidelines. Volume 4 describes the material property library, MATPRO. It contains descriptions of the material property subroutines available for severe accident analysis. Volume 5 documents code assessments. It summarizes the improvements made to various versions of the code and the effect of these improvements on code calculations. A presentation is made of the comparisons of code calculations of a wide range of severe fuel damage experiments with the measured results of these experiments. Also presented are code calculations of the TMI-2 accident and calculations of severe accidents in typical PWRs and BWRs.

## 1.5 Organization of Volume 3

The purpose of this volume is to help educate the code user by documenting the modeling experience that has been accumulated from developmental assessment and application of the RELAP5 and SCDAP codes. This information includes application experience that indicates what has been found to work or not to work. Where possible, definite recommendations of approaches known to work are made and approaches known not to work are pointed out as pitfalls to avoid.

Section 2 of this volume describes the type of core structures that can be modeled with SCDAP/

RELAP5-3D©. Section 3 provides user guidelines. Section 4 describes nodalization guidelines. Section 5 provides problem control and output editing. Section 6 discusses the installation process, and Section 7. provides references. Appendix A of this volume documents SCDAP input requirements for SCDAP/RELAP5-3D©.

# 2. CORE STRUCTURES

The core structures represent those portions of the reactor core which are solid at the beginning of the analysis. This may include fuel rods, control rods, flow shrouds, simulator rods, or channel boxes.

## 2.1 Fuel Rod

The fuel rod behavior model calculates the thermal, mechanical, and chemical response of fuel rods during severe accidents. The fuel rod behavior models consider nuclear heat generation, temperature distribution, zircaloy cladding oxidation, fuel deformation, liquefaction, and fission product release. Nuclear heat generation, in combination with the heat generation of cladding oxidation, determines the fuel rod temperature. The rod temperature is computed by a two-dimensional finite difference scheme. The oxidation heat of zircaloy is the dominant heat source after temperatures reach 1,500 K. Cladding deformation is based on mechanical models developed for FRAP-T6[12] and FRAPCON-2.[13] The model considers both axisymmetric cladding collapse or ballooning and asymmetric localized ballooning. The melt, flow, and refreezing of liquefied U-O-Zr is also considered. The liquid material is assumed to flow as an axisymmetric slug depositing both heat and a frozen crust upon the underlying $ZrO_2$ layer. The release of inert gases (krypton, xenon, helium) and volatile fission product (cesium, iodine) is modeled using the PARAGRASS[3] model.

## 2.2 Ag-In-Cd Control Rod

Control rod temperatures are computed using the same heat conduction model as the fuel rods. User-specified nuclear heating, chemical heating caused by oxidation of the zircaloy guide tube and stainless steel cladding, and convective and radiative heat transfer from the coolant and adjacent fuel rods are considered. The melting and relocation of control rod materials are described in the following manner. If the stainless steel is below its melting temperature, no relocation of molten Ag-In-Cd occurs. If the guide tube melts, or is breached, molten absorber moves through the breach in the zircaloy guide tube and moves as a film on the outside of the guide tube. Unlike the flow of molten Zr-U-O for fuel rods, the momentum and energy equations are not solved to describe the freezing of the molten Ag-In-Cd; rather, the material freezes when it reaches a lower elevation where the guide tube temperature is 200 K less than the solid temperatures of Ag-In-Cd. For subsequent heatup and melting of stainless steel and zircaloy, the molten material relocates internally downward within the oxidized $ZrO_2$ on the guide tube, filling up the voids formed by the relocation of molten Ag-In-Cd. The molten mixture of stainless steel and zircaloy will remain contained within the $ZrO_2$ shell until the $ZrO_2$ is either melted, allowing the molten mixture to flow downward in the flow channel until it freezes, or is shattered upon reflood.

## 2.3 Flow Shroud

The structures internal to the core other than fuel and control rods can be modeled using the basic heat conduction equation. Heat generation can be user-specified and oxidation related. The structures can be defined by multiple layers of materials, with the oxidation and relocation of exterior layers caused by melting considered. Zircaloy layers are oxidized using the same kinetics as described for fuel rods. The molten zircaloy relocates downward to a region where the structural surface temperature can also be modeled; however, oxidation rate equations must be user-specified and no material relocation or loss of geometry can be considered. Both melting and non-melting models can be used for the structures outside the core as well, since the same material limitations apply.

## 2.4 Simulator Rod

The simulator rod is used in out of pile experiments to simulate the behavior of fuel rods during a severe accident scenario. The simulator rod is heated electrically by tungsten wire at the center. The simulator rod behavior model calculates the thermal, mechanical, and chemical response of simulator rods during severe accidents. The model considers electric heat generation, temperature distribution, zircaloy cladding oxidation, and fuel deformation and liquefaction. Electric heat generation, in combination with the heat generation of cladding oxidation, determines the fuel rod temperature. The rod temperature is computed by a two-dimensional finite difference scheme. Cladding deformation is based on mechanical models developed for FRAP-T6 and FRAPCON-2. The melt, flow, and refreezing of liquefied U-O-Zr are also considered.

## 2.5 BWR Control Blade/Channel Box Model

Analyses of the DF-4 and CORA experiments have shown that the effects of $B_4C$/stainless steel interactions, as well as stainless steel/zircaloy interactions, must be included to predict control blade relocation accurately. Melting of a control blade begins at the inner surfaces of the absorber rodlets where stainless steel reacts with $B_4C$. The absorber rodlets fail at a temperature that is lower than the melting temperature of pure stainless steel. Stainless steel from the control blade then relocates downward and forms a blockage between the control blade and channel box, where it reacts with the zircaloy. The zircaloy channel box adjacent to the stainless steel blockage enters into the formation of a eutectic mixture and fails at a temperature that is much lower than the melting of pure zircaloy.

## 2.6 $B_4C$ Control Rod Model

The $B_4C$ control rod model has been retained in the code because some reactors make use of cylindrical $B_4C$ control rods wherever possible, the use of the control blade channel box model, described in Section 2.5 is recommended.

Control rod temperatures are computed using the same heat conduction model as the fuel rods. User-specified nuclear heating, chemical heating caused by oxidation of the zircaloy guide tube and stainless steel cladding, and convective and radiative heat transfer from the coolant and adjacent fuel rods are considered. The melting and relocation of control rod materials are described in the following manner. If the stainless steel is below its melting temperature, no relocation of molten absorber occurs. If the guide tube melts, or is breached, molten absorber moves through the breach in the zircaloy guide tube and moves as a film on the outside of the guide tube. Unlike the flow of molten Zr-U-O for fuel rods, the momentum and energy equations are not solved to describe the freezing of the molten absorber; rather, the material freezes when it reaches a lower elevation where the guide tube temperature is 200 K less than the solidus temperature. For subsequent heatup and melting of stainless steel and zircaloy, the molten material relocates internally downward within the oxidized $ZrO_2$ on the guide tube, filling up the voids formed by the relocation of molten $B_4C$. The molten mixture of stainless steel and zircaloy will remain contained within the $ZrO_2$ shell until the $ZrO_2$ is either melted, allowing the molten mixture to flow downward in the flow channel until it freezes, or is shattered upon reflood.

# 3. SCDAP/RELAP5-3D© USER GUIDELINES

## 3.1 SCDAP/RELAP5-3D© Card Number Input

The SCDAP/RELAP5-3D© input structure has traditionally comprised three different styles--RELAP5 card number, SCDAP unformatted, and COUPLE fixed format. While the SCDAP unformatted input was free-form, it provided no capability for input checking or error recovery during the input process. The COUPLE input scheme required that the input be right-justified within a specified range of columns. This input structure made creation of severe core accident analysis input decks time-consuming, frustrating, and unreliable due to extremely primitive levels of input checking. The input had virtually no error detection, and bad input often ended in floating point exceptions and I/O errors. Resolving input errors often required knowledge of the code structure, use of debugging tools, and use of code debug printout. Since RELAP5-style card-number input provided significantly greater flexibility in input checking, and since users are already familiar with this style of input, all SCDAP/RELAP5-3D© input has been converted to use RELAP5-style card-number input.

Input for SCDAP/RELAP5-3D© is processed on three levels, (a) input echo; (b) individual card, or R-level processing; and (c) initialization, or I-level processing. This input philosophy provides the maximum diagnostic information for each input submittal. During input echoing, the input deck is echoed to the output file; and cards with the same card numbers (replacement cards) are detected. At the R-level processing, the cards are read in and, wherever possible, basic range checking is performed to be sure that the input variables fall within physical limits. At this input level the code is able to provide only primitive input checking, since information is available only about the current card. During the initialization, or I-level processing, more global range checking is performed; and the code is able to verify self-consistency between cards.

As a minimum, all input will be subjected to four comparative checks: (1) physical/code limits, such as a fuel pellet radius greater than the inner cladding radius, (2) consistency of input, such as a radial node omitted at a material interface, (3) number of words on a card, and (4) variable type. A fifth check, for range of normal use, will also occur during input processing wherever applicable. Input violations of physical and/or code limits, consistency of input, number of words on a card, and variable type will result in an input error but will not abort input processing. Wherever possible, input data that has previously been shown to cause a code abort are now tested, and diagnostic messages issued. Rejected input will be identified and reset to a benign value to allow complete input processing. The selected ranges of allowable input are listed with the card input descriptions in Appendix A. This appendix also contains additional information on the type of checks that will be performed.

Sequential expansion, as found in RELAP5, is used wherever possible. In sequential expansion, sets of data used to specify parameters are followed by an integer, which specifies the range over which the parameters should be applied. As an example, if a data set can be applied to each axial node of a component, then the integer would be the final axial node over which the data were to be applied.

Utilization of sequential expansion significantly decreases the size of an input deck and is a technique which RELAP5 users have applied for many years. Additional examples may be found in Reference 12.

## 3.2 Input Preparation

Attention to detail in preparing, documenting, and checking the input limits errors and provides a valuable model reference for tracking error corrections and subsequent model improvements. By using standardized input format and conventions, input errors are easier to detect. The following sections discuss standard procedures for model documentation and quality assurance, input deck arrangement, and conventions.

### 3.2.1 Input Deck Arrangement

The code accepts data based on the "card number" specified in the first field on each line of input. For a given card number, the code accepts the input parameters specified in the code manual as sequences of floating point, integer, and alphanumeric entries. On any given card, the data entries must appear in the proper sequence and be separated by one or more blanks. The cards may appear in any order, as long as all required cards and data entries are present. If a card number is duplicated in the input listing, the code identifies it as a "replacement card" and uses the information on the last card entered with that number.

As stated above, the input deck cards may appear in any order. In practice, however, arranging the cards in a logical manner is preferred. At the INEEL input decks typically start with the title, job control, and time step control cards. These are followed in sequence by the minor edit requests, trip specifications, hydrodynamic components, heat structures user-input data tables, control variables, and reactor kinetic specifications. An input deck is generally arranged by increasing card numbers when this arrangement is used. Within each of the above groups, data are similarly arranged in order of the card numbers (e.g., the trips are listed in numerical order).

A well-organized input deck includes comment cards that aid interpreting the input from a printed listing. Comments may be inserted through the use of the asterisk (*). On any line, all entries following an asterisk are assumed to be comments. With this format, an analyst will spend a minimum amount of time counting fields and searching through the manual to understand the input.

### 3.2.2 Model Input Debugging

The input processing routines provide excellent error-checking and error-interpretation capabilities. Input processing error checking is invoked when executing both new- and restart-type problems. All model input errors result in the generation of an informative error message. The presence of one or more input errors results in job termination and a message that the termination was due to input error. As a word of caution, the SCDAP/RELAP5-3D© error-checking functions are primarily intended to check for compliance with the input data requirements. Secondarily, checking is performed for model consistency (e.g., that fuel rod diameter does not exceed pitch). However, the input error-checking function may not uncover basic input errors such as incorrectly specifying a radius of 0.050 m as 0.50 m. Therefore, successful completion of SCDAP/RELAP5-3D© input processing should not be considered a replacement for a quality assurance activity such as a 'workbook', as described in the RELAP5 user guidelines.[12]

An efficient method for debugging a new SCDAP/RELAP5-3D© input deck is described as follows. The complete model is first assembled into a single file and the model is executed in either the transient or steady-state modes as specified on Card 100. Either the INP-CHK or the RUN option may be selected on Card 101. A typical new input deck will likely contain many input errors so the execution will result in generation of a series of error messages. It is common for one actual error to propagate into the generation of multiple error messages. Therefore, the list of error messages generated will in general be much longer than the actual number of errors in the model. The user should read and consider each of the error messages in the order they were generated. This process results in one of the following determinations for each of the error messages: (a) the message clearly indicates an error in the deck and the resolution is clear, (b) the message is found to be caused by the existence of a previous error and is expected to be resolved when the primary error is corrected, and (c) the reason the message was generated is not clear. In practice, the error messages are very informative and the actual input errors are obvious to the analyst. A significant effort can be expended tracing the source of each error message. Instead, it is more efficient to survey the error messages, correct the obvious errors, and again execute the model. As a rule of thumb, only about one third of the error messages generated are caused by actual errors; the remainder are second-generation messages resulting from the primary errors. This iterative process proceeds rapidly to the removal of all input errors. Experience shows that a large input deck that has been entered with moderate care can be debugged with this process in about five iterations.

The iterative debugging process described in the previous paragraph can be much easier if the output of the debugging runs are reviewed on a terminal by an editor capable of searching for data strings. All input error messages are preceded by a string of eight asterisks (********) and the removal of all errors results in the generation of the message "Input processing completed successfully". The user should be cautioned that even when there are no input error messages (marked by eight asterisks), there may still be input warning messages (marked by eight dollar signs). Although not fatal, these messages may assist in identifying additional errors.

The user should be aware that the input processing is subdivided into several sections of data checking that are performed in sequence. Depending on the nature of the errors found, the job may be terminated at the end of one of the sections before all of the error-checking sections have been executed. In this instance, only error messages for the sections that have been checked will appear. When these errors have been corrected and the checking proceeds to the next section, the number of error messages may increase. In other words, the analyst should realize that in this iterative process the number of error messages may not monotonically decrease.

## 3.3 Problem Execution

When the input deck has successfully passed input processing, an initial time edit will be generated by the code. If the RUN option is selected, problem execution proceeds from the conditions specified in the initial edit. The initial edit will be identified as zero time for NEW problems and as the time of the restart edit for RESTART problems.

### 3.3.1 Time Step and Edit Selections

The problem execution is controlled by the options specified on the 201 - 299 time step control cards. These cards specify the time step sizes and output features desired as the problem progresses from one time interval to the next. Card 201 specifies these options and the end time for the first time interval, Card 202 for the second time interval, and so on. Subdividing the problem into time intervals facilitates modifying the execution to suit the expected nature of the problem. For example, consider the case of a modeling action (such as closing a valve or tripping a pump) that is of particular interest and may slow the calculation at a given time (say 10 seconds). For this case, a first execution interval might be selected to end at 9 seconds. The second interval might include a reduced time step, and perhaps increased edit and plot frequencies, from 9 to 15 seconds. After 15 seconds, a third interval would then be used to return the time step and edit options to their original values. Note that execution is terminated if the problem time reaches the end of the last interval specified on the 201 - 299 cards.

For each time interval, minimum and maximum time steps are specified. The code will attempt to execute the problem at the maximum time step. The first time step taken will be at the maximum value. The user is cautioned to use a small maximum time step size when first executing a model for which gross approximations of initial conditions have been specified. Time step size is automatically reduced based on a number of tests. The material Courant limit may not be violated. Mass, fluid property, quality, and extrapolation errors are monitored in each calculational cell and the time step is reduced if errors exceed internally preset limits. The major edit output indicates the criteria and model region causing time step reduction. This indication can be useful for improving model performance.

The code accomplishes time step reductions by repeated division by two until the errors are within acceptable limits, the minimum time step size is reached, or a failure is encountered. The severe accident subcode, SCDAP, now has the ability to impact the time step selection as well. Phenomena which have more impact during severe accident analysis, such as radiation heat transfer, can apply significant stress to the code. These phenomena can now be used to force SCDAP/RELAP5-3D© to repeat the time advancement with a reduced time increment.

## 3.4 Plot Variables

One of the primary resources for an analyst using the SCDAP/RELAP5-3D© code is the plot file. Severe accident transients, by the very nature, have parameters which are changing rather dramatically with time, and system ‘snapshots’, such as are provided by the major edits, reveal only part of the story. The severe accident analyst is encouraged to make extensive use of the ability to plot parameters from the restart/plot file. Specification of the parameters of interest are done by use of ‘208’ cards, and the code user is referred to Appendix A of this report for details on the use of these cards.

## 3.5 Guidelines for Late Phase Damage Progression

The uncertainties involved in modeling the late phase damage progression make it useful to perform bounding studies on the calculated times of molten pool slumping and failure of the lower head. The areas of modeling with large uncertainty include:

- Strength and configuration of solidified material that supports a pool of molten core material.
- Fragmentation temperature of embrittled fuel rods that are quenched.
- Flow area of break resulting in creep rupture failure in piping system.
- Configuration of slumping molten material.
- Heat transfer coefficient between debris and the lower head of the reactor vessel.

A parameter for each of these areas of modeling can be defined by the code user so that a series of analyses can be performed to bound the possible behavior of the reactor. This section provides guidelines for the range of values of these parameters in order to calculate the range of possible reactor behavior.

An integer parameter is provided on SCDAP input Card 40001100 to provide an estimate of the range of time in which a molten pool slumps to the lower head. If this parameter is set to a value of one, then the molten pool is considered to slump to the lower head whenever material at the periphery of the core has become molten. In this modeling option, solidified material at the periphery of the core is considered to have no strength for supporting a molten pool. This value of the input parameter provides an estimate of the earliest possible time of molten pool slumping. If the parameter on Card 40001100 is set to a value of zero, then the crust supporting the molten pool is considered to always have the strength necessary for supporting a molten pool. The molten pool does not slump to the lower head until its supporting crust at some point is calculated to melt. This value of the input parameter provides an estimate of the latest possible time for slumping of the molten pool. For both values of the input parameter, if the molten pool is calculated to slump, all of the molten material is calculated to slump. The assumption is applied that the initial point of failure of the crust is eroded to a depth sufficient to allow drainage of the entire molten pool. This assumption and the two types of slumping behavior defined by Card 40001100 are an interim solution until a model is implemented for calculating the structural integrity of the crust

Embrittled fuel rods are considered to fragment when their temperature decreases to a value less than the user-defined fragmentation temperature. The fragmentation temperature is user-defined because the code does not have a mechanistic model for the timing of fragmentation. The most likely time for embrittled fuel rods to fragment is during the period of rapid temperature change that occurs when the mode of heat transfer at the cladding surface changes from film boiling to nucleate boiling. The thermal stresses in the cladding are maximum during this period of time. An upper bound value on fragmentation temperature is estimated to be the temperature at which the mode of heat transfer at the surface of fuel rods being quenched changes from film boiling to transition boiling. The lower bound of the fragmentation temperature is estimated to be the temperature at which the nucleate boiling mode of heat transfer occurs, which is near the saturation temperature of water. Other mechanisms for fuel rod fragmentation may be possible. If the user identifies one of these other mechanisms being in operation, then a fragmentation temperature appropriate for this mechanism should be defined. The user-defined value for fragmentation temperature has no influence on calculated results for the case of severe accidents in which no embrittled fuel rods are cooled below the upper bound value of the fragmentation temperature or in which all of the fuel rods are cooled to temperatures less than the lower bound value of fragmentation temperature. If fuel rods with cladding that is calculated to be embrittled are cooled to a temperature less than the fragmentation temperature, then the fuel rods are considered to disintegrate into porous debris. The upper bound on the calculated extent of core fragmentation is obtained by defining the fragmentation temperature to have its upper bound value. The lower bound on the calculated extent of core fragmentation is obtained by defining the fragmentation temperature to have its lower bound value.

The flow area of a break is defined by the RELAP5 input card for the valve component that represents the break. The break size is estimated to range from 25% to 200% of the flow area of the pipe that broke. Creep rupture calculations must first be requested for each possible location in the reactor piping system at which creep rupture may occur. The locations for which creep rupture is to be performed are defined on RELAP5 Cards 21000110 (no COUPLE) and 21000000 (with COUPLE). Then after the calculations have identified the time and location of the first creep rupture, the calculations are repeated with a break being defined for the location with a creep rupture.

The extent of breakup of material slumping from a molten pool may either be defined by the user or calculated by the code's fuel-coolant interaction model. If the stream of slumping molten material remains as an intact stream, then heat is not transferred from the molten material as it slumps. The molten material is at the same temperature when it impacts the lower head as it was when it was in the molten pool in the core region. In addition, the material that slumps to the lower head is defined to have no porosity. As a result, the lower head of the reactor vessel may heatup rapidly. If the molten material breaks into small droplets as it passes through liquid water, then the molten material is cool when it impacts the lower head. In addition, the material is considered to have open porosity that can be filled with water. The heat transferred from the small droplets of molten material to water may cause a significant increase in pressure in the primary coolant system.

## 3.6 Noncondensable Model

The noncondensable model is implemented by specifying a noncondensable gas type on control Card 110 and indicating a noncondensable quality on one or more volume initial condition cards. A mixture of noncondensable gases may be specified by indicating more than one gas type on Card 110 and specifying their mass fractions on Card 115. It should be noted that only one noncondensable gas mixture may be used in a problem, although the fractions of each gas type may change in each hydrodynamic volume, and the noncondensable gas must be hydrogen (or include hydrogen in the case of a mixture). This means that if nitrogen is present in one part of the system and hydrogen is present in another, then the system has a mixture of hydrogen and nitrogen, with the mixture consisting of 100% nitrogen and 0% hydrogen in one location and a mixture of 0% nitrogen and 100% hydrogen in another.

The noncondensable model assumes the gas is tracked with the vapor phase. Furthermore, the resulting gas-steam mixture is assumed to be isothermal (i.e., the gas and steam are in thermal equilibrium). A total pressure is calculated for the gas-steam mixture; the partial pressure of steam is available as a standard output variable.

## 3.7 BWR Channel Box User Guide

This section describes the input data that the user must specify on SCDAP input cards for the BWR control blade and channel box component. Also, information is provided to help the user interpret the printed output.

### 3.7.1 BWR Blade/Box Cards

The specific SCDAP input cards for the BWR control blade and channel box component are documented in Appendix A. This section provides additional information to help the user prepare data for the input deck. All descriptions in this section refer to the new SCDAP input format with RELAP5-style card numbers (see Section A. l of Appendix A).

Hardwired default failure (liquefaction) temperatures are used to account for the effects of eutectic interactions between $B_4C$/stainless steel and stainless steel/zircaloy. Eutectic interactions are modeled by using failure (liquefaction) temperatures that are less than the melting temperatures of the pure materials.

The metal/water reaction parameters on Card 40003100 affect the $B_4C$ and zircaloy oxidation calculations. The user must specify a maximum fraction of $B_4C$ in each node that can react. This maximum fraction is used by the advanced $B_4C/H_2/H_20$ chemistry package to control the mass of $B_4C$ available for the chemical equilibrium calculations.

The control blade and channel box dimensions specified by the user on Cards 40CC0200 and 40CC0300 are sketched in Figure 3-1. The actual control blade radial dimensions shown in the top of Figure 3-1 are converted by the model into the equivalent slab geometry shown in the bottom of the figure. The equivalent slab thicknesses are calculated so that the cross-sectional area of each layer in the equivalent slab geometry is identical to the cross-sectional area in the actual geometry. The distance between the channel box and the first row of fuel rods (dimension 7 in Figure 3-1) is used in the relocation calculations to determine when the region on the fuel-bundle side of the channel box is blocked.

As is the case for all other SCDAP components, the internal modeling for the BWR blade/box component is performed using a local set of dimensions that describes the single blade/box structure shown in Figure 3-1. However, the BWR blade/box component can be used to represent many copies of this individual blade/box structure by specifying the value on Card 40CC0100. If a value of 1 is specified on

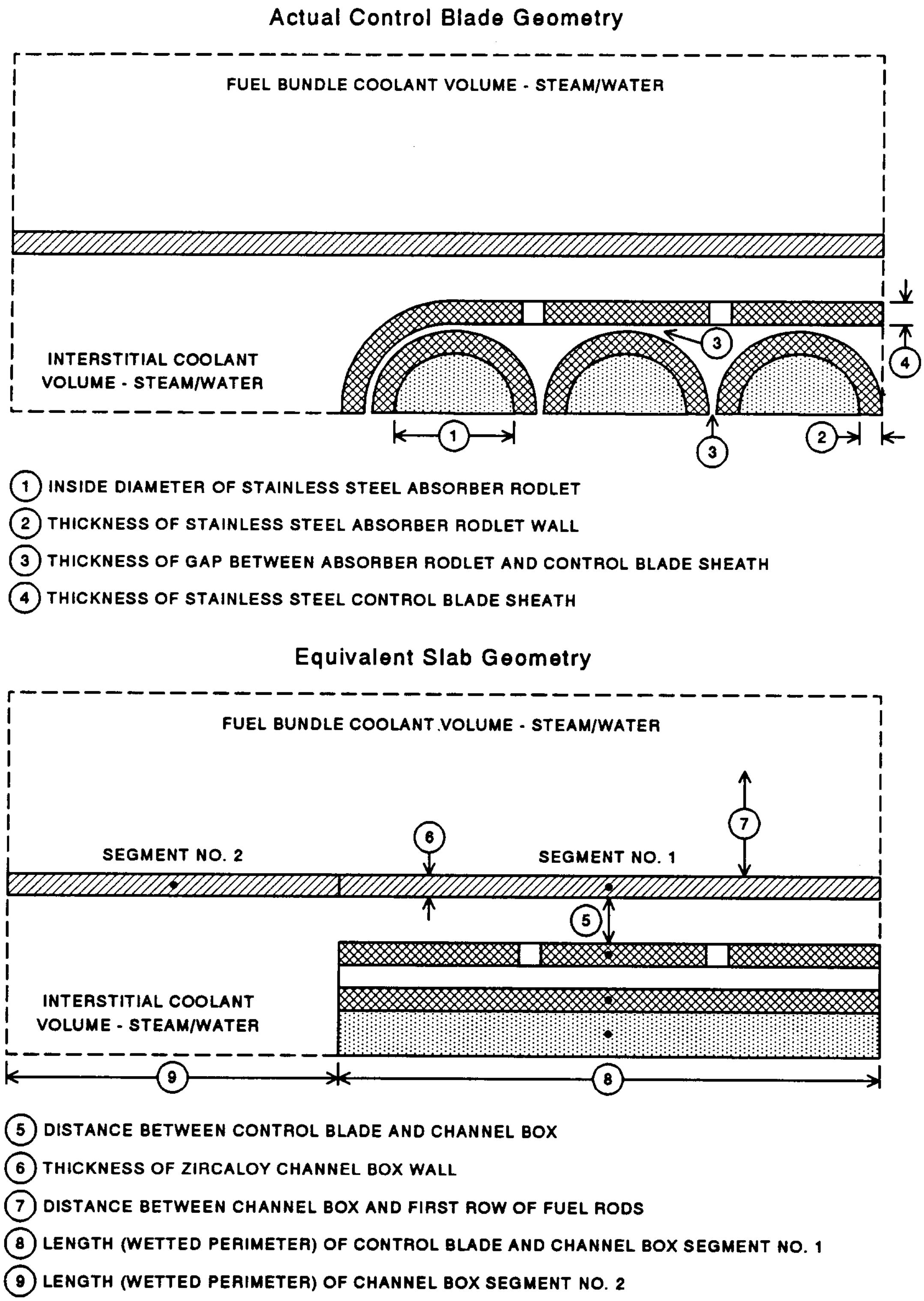


**Figure 3-1.** BWR control blade and channel box dimensions specified by the user.

Card 40CC0100, then the component will perform calculations for half of a control blade and two channel box segments with lengths as indicated in Figure 3-1 (dimensions 8 and 9).

The geometric view factors specified on Card 40CC0300 are for radiation between the channel box and the control blade, which is modeled internally by the BWR blade/box component. These geometric view factors must be calculated by the user using the geometry sketched at the bottom of Figure 3-1. The sense of direction is from the channel box to the control blade, i.e., the view factors are based on the areas of the channel box segments.

Initial conditions for the BWR blade/box component are specified on Cards 40CC0500 and 40CC0601 through 40CC0699. The three oxide thicknesses on Card 40CC0500 apply to all axial nodes. The initial stainless steel oxide layer must be specified nonzero because this value is used as a denominator in the stainless steel oxidation calculations. This restriction does not apply to the initial $ZrO_2$ layers; they may be specified zero. The initial control blade temperatures specified for each axial node on Cards 40CC0601 through 40CC0699 (Word 1) apply to all three radial nodes. The initial channel box temperatures specified for each axial node on Cards 40CC0601 through 40CC0699 (Word 2) apply to both channel box segments.

If fuel rod or electrically-heated simulator rod components can receive molten material from a BWR blade/box component, then this information is specified on Cards 40CC0701 through 40CC0799 and 40CC0801 through 40CC0899. Cards 40CC0701 through 40CC0799 apply to radial spreading from channel box segment No. 1 while Cards 40CC0801 through 40CC0899 apply to segment No. 2. The mass fractions of molten material from channel box segment Nos. 1 and 2 are used to determine how molten material is proportioned between multiple fuel or simulator rod components that are located adjacent to the same channel box segment.

The mass fractions on Cards 40CC0701 through 40CC0799 and 40CC0801 through 40CC0899 can be used to represent radial spreading that occurs initially into the first row of fuel rods and later into the remainder of the fuel bundle. For example, assume the BWR fuel assembly shown in Figure 3-2 is modeled with SCDAP using one BWR blade/box component (No. 1) and three fuel rod components (Nos. 2, 3, and 4). If the following cards are specified for BWR blade/box radial spreading:

```
*crd.no     comp.no     frac.segl
 40010701   2           0.999
 40010702   4           0.001
 *crd.no    comp.no     frac.seg2
 40010801   3           0.999
 40010802   4           0.001
```

then almost all molten material from channel box segment No. 1 (99.9%) will initially be received by fuel rod component No. 2 and almost all molten material from channel box segment No. 2 (99.9%) will initially be received by fuel rod component No. 3. However, the BWR blade/box relocation logic adjusts the mass fractions on Cards 40CC0701 through 40CC0799 and 40CC0801 through 40CC0899 when one of the fuel rods becomes blocked at an axial level by cohesive, rubble, or molten debris. Referring to the above example, after fuel rod component No. 2 becomes blocked at an axial level by debris, the mass fraction on Card 40010701 (0.999) is changed to 0.0 and the mass fraction on Card 40010702 (0.001) is increased to 1.0. Subsequently, all molten material from channel box segment No. 1 will be received by fuel rod component No. 4.

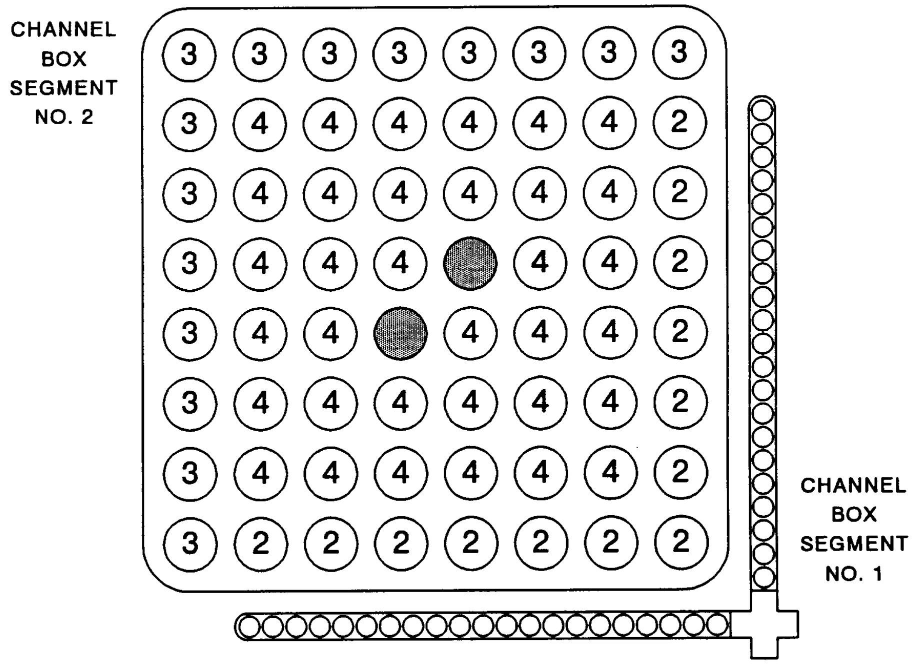


**Figure 3-2.** Example arrangement of fuel rod components.

### 3.7.2 Radiation Enclosure Cards

Each BWR blade/box component must be associated with two SCDAP radiation enclosures. One enclosure is for the fuel-bundle side of the channel box and the other is a “dummy” enclosure for the interstitial side of the channel box. Radiation calculations on the fuel-bundle side of the channel box are performed within the SCDAP radiation model using independent surfaces to represent the two channel box segments. The dummy enclosure on the interstitial side of the channel box is not actually used to perform radiation calculations between the channel box and the control blade (these calculations are performed internally by the BWR blade/box model), but this enclosure is needed to initialize properly the hydrodynamic calculations for the interstitial volume. If the user does not define both SCDAP radiation enclosures for each BWR blade/box component, an error message is printed and execution is terminated after the completion of input processing.

When a BWR blade/box component is included within a radiation enclosure, the view factors and path lengths for that enclosure must be specified by the user on Cards 49NN1001 through 49NN1099 and 49NN1101 through 49NN1199. Because the two segments on the fuel-bundle side of the channel box are treated independently, view factors between channel box segment Nos. 1 and 2 can be calculated and specified, if necessary.

In the radiation enclosure section of an input deck (see the following example), the component number of a BWR blade/box component must be listed three times on Cards 49NN1000. The first two BWR blade/box entries must be consecutive and are part of a radiation enclosure that represents the fuel-bundle region. These first two entries refer to segment Nos. 1 and 2, respectively, on the fuel-bundle side of the channel box. The third BWR blade/box entry must be on a separate Card 49NN1000 that represents the dummy enclosure for the interstitial side of the channel box. The input cards that define this dummy enclosure must follow the cards that define the fuel-bundle radiation enclosure.

For example, suppose there are two components in a SCDAP input deck and component No. 1 is a fuel rod and component No. 2 is a BWR blade/box. To model radiation between the fuel rods and the two channel box segments, the user must define enclosure No. 3 for the fuel bundle side of the channel box, followed by dummy enclosure No. 4 for the interstitial side of the channel box, using the following format:

```
*crd.no      name          type
49010000     fuel          bundle
*card. no    comp.nos
49011000     1   2  2
*crd.no      view.factor
49011001     0.2818     0.6782     0.0400
49011002     0.9400        0.0   0.0600
49011003     0.2094        0.2267   0.5639
*crd.no      path. length
49011101     0.001         0.005   0.015
49011102     0.005         0.0     0.015
49011103     0.015         0.015   0.010
*crd.no      name          type
49020000     dummy         bundle
*crd.no      comp.nos
49021000     2
*crd.no      view.factor
49021001     1.0
 *crd.no     path.length
 49021101     0.0
```

Component No. 2 (BWR blade/box) is listed twice on Card 49011000 and once on Card 49021000 of the above example. The view factor and path length arrays for enclosure No. 3 have two sets of entries for component No. 2. The second value on Card 49011001 (0.6782) is the view factor from the fuel rods to channel box segment No. 1. The third value on Card 49011001 (0.0400) is the view factor from the fuel rods to channel box segment No. 2. The third value on Card 49011002 (0.0600) is the view factor from channel box segment No. 1 to channel box segment No. 2. For enclosure No. 2, the view factor on Card 49021001 and the path length on Card 49021101 are dummy values.

### 3.7.3 Minor Edit Requests

The BWR blade/box variables that can be printed at "Minor Edits" or written to the restart-plot file are described in Appendix A, Section A4.10.5, Table A4-7. Although the variable names are identical to those used for other SCDAP components, these definitions apply only to the BWR blade/box components. These variables are "Expanded Edit/Plot Variables" and are not written to the restart-plot file by default. To write these variables to the restart-plot file, a RELAP5 Card 2080XXXX with the appropriate name and index must be added to the input deck. For all variable names, "Index" is defined as: ii = radial node number, kk = axial node number, and jj = SCDAP component number.

The locations of the BWR blade/box radial nodes for temperature variable CADCT are shown in Figure 3-3. The intact structures of the control blade and the channel box are at radial locations 2-4, 6, and 12. The temperatures defined for radial locations l and 14 are average surface temperatures that are used as boundary conditions for the RELAP5 hydrodynamic calculations. The temperatures at the other radial locations (5, 7, 8-11, and 13) have unique values only when those nodes are blocked and filled with relocated material; otherwise they are set equal to the temperature of the adjacent intact structure.

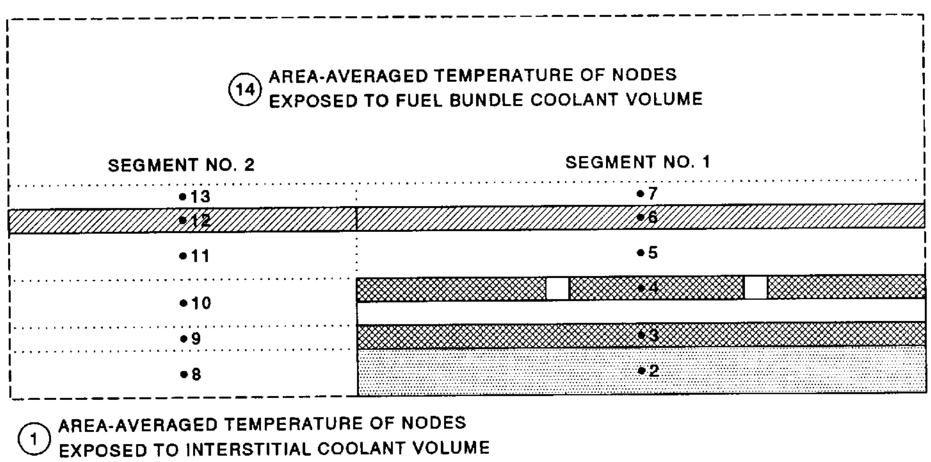


**Figure 3-3.** Radial node numbers used to print BWR blade/box temperatures at minor edits.

The variable DAMLEV is defined so that it can be used to control gas flow between the interstitial and fuel bundle coolant volumes after the channel box wall has failed. This is accomplished by using RELAP5 servo valve components with valve areas calculated by control system components based upon the values of DAMLEV.

### 3.7.4 Restart Calculations

A BWR blade/box calculation can be continued from a previous calculation by specifying the problem type on RELAP5 Card 100 as “restart” and the appropriate restart number on RELAP5 Card 103. Information from the restart-plot file is used to initialize the variables for BWR blade/box components.

# 4. NODALIZATION GUIDELINES

## 4.1 Core Nodalization Guidelines

Requirements for the nodalization of the reactor core for a severe accident analysis is significantly different from that needed for a comparatively simple hydraulic analysis. Section 3.9 discussed the reasons why a one- or two-channel analysis technique, which has been successful for analysis of thermal-hydraulic phenomena, is not appropriate for the phenomena associated with early phase severe accident conditions.

The nodalization of the core with five radial segments and ten to twenty axial nodes is considered to result in an adequate calculation of the core behavior during late phase damage progression. The nodalization sensitivity study presented in Reference 19 showed that the calculated time of slumping of the molten pool may be 7% later using twenty axial nodes instead of ten axial nodes. The nodalization sensitivity study also showed that if surge line rupture was ignored (high pressure case) the use of three radial segments instead of five resulted in an incorrect calculation of the core location where late phase damage progression began and resulted in a significantly earlier calculated time for the beginning of late phase damage. Each radial core segment should contain one SCDAP component to represent the fuel rods in that segment and one SCDAP component to represent the control rods/control blades. For PWRs, each radial core segment should contain one RELAP5 control volume representing the fluid in that segment. For BWRs, each radial segment should contain two RELAP5 control volumes, one representing the fluid flowing through the fuel assemblies and the other representing the fluid flowing between the fuel assemblies. Each RELAP5 control volume should be divided into as many subvolumes as axial nodes in the SCDAP components, and the subvolumes should overlay the axial segments of the SCDAP components. The reader is referred to the nodalization study documented in Volume 5 of this report for additional details.

## 4.2 Ex-vessel Example Nodalizations

This section provides example SCDAP/RELAP5-3D© nodalizations for PWRs. The purpose of this section is to provide guidance for ex-vessel nodalization that may be used for analyzing a wide variety of small break LOCAs and operational transients. The user is cautioned that no model is generally applicable for simulating all transient scenarios. Care should be taken so that modeling and nodalization are appropriate for the particular application.

For economic reasons, the numbers of hydrodynamic cells and heat structure mesh points, in general, should be minimized. The computer run time needed to execute a problem simulation is determined almost completely by the number of hydrodynamic cells in the model. The number of heat structures generally increases in tandem with the number of cells. Therefore, a major economic benefit is gained by limiting the number of hydrodynamic cells in a model. Some additional economic benefit may be obtained by minimizing the number of mesh points within the heat structures. Limiting the number of other model features (such as trips and control variables) provides only minimal economic benefits. An additional motivation for employing the largest calculational cells possible, is that when small cells are used, the time step size is reduced as a result of the material Courant limit. The Courant limit, discussed in Reference 12, limits the calculational time step based on the ratio of cell length to fluid velocity.

The process of minimizing model size must always consider the phenomena to be modeled; minimizing must not proceed past the point where important phenomena are excluded from the simulation. This consideration is complicated because the importance of phenomena varies from one region of the model to another and is strongly affected by the transient to be simulated. For example, the important model regions and simulation phenomena for small and large break loss-of-coolant accidents are dramatically different; therefore, appropriate modeling for these two sequences varies dramatically.

In summary, the modeler should select the minimum number of hydrodynamic cells and heat structure mesh points needed to calculate the important phenomena for the simulated transient. This guidance suggests that a general model (i.e., one that is to be used to simulate many different types of transients) should contain sufficient noding detail for all phenomena anticipated. If the important phenomena are uncertain, a detailed noding scheme should be employed. Conversely, if the important phenomena are well known, nodalization of the noncritical model regions may be simplified. If sufficient time and funds are available, it is recommended that a general model of a reactor system be assembled first. Analysis using the general model will then provide the information needed to determine what model simplifications are appropriate. The following sections provide additional guidance concerning hydrodynamic cell and heat structure sizing. General suggestions for appropriate noding may be inferred from Section 4.

### 4.2.1 Ex-Vessel Hydrodynamic Cell Size

As discussed above, large hydrodynamic cell sizes should be used for economic reasons. However, in each region of the model, the detail of the calculational cells must be sufficient to allow the simulation of important regional thermal-hydraulic phenomena. As a starting point, cell lengths for ex-vessel hydrodynamic volumes of 1 to 3 m (3 to 10 ft.) are recommended in phenomena-dominating regions (e.g., pressurizer, and steam generator) of a light water reactor model. Cells of much longer lengths are appropriate in less important regions of the model (e.g., the feedwater train and steam lines). The cell sizes presented in these applications may be taken as guideline recommendations for modeling light water reactors. For totally new applications or where the calculation results may be particularly sensitive to the model discretization, a convergence study is recommended to ensure that a proposed nodal layout is adequate.

Good modeling practice includes blending the transition from regions of small cells to regions of large cells. For this blending, it is recommended that the volumes of adjacent cells not differ by more than an order of magnitude.

Other considerations affecting cell size selection are the locations of natural boundaries, flow connections, and instruments within the prototype fluid system. Good modeling practice includes placing junctions at natural fluid system boundaries and at flow loss features (such as support plates, grid spacers, bends, and orifices). Using this practice, the flow loss is placed at the proper location with respect to the fluid volumes. For similar reasons, the placement of junctions at flow connection points is a good practice.

Cell size selection should also consider placing model features at prototypical instrument locations (e.g., placing a cell center at the location of a pressure tap or a junction at the location of a flow meter). This practice facilitates the use of the code output because the calculated and measured data are directly comparable without further effort.

### 4.2.2 Steam Generator Primary Nodalization

The nodalization for the primary side of two types of steam generators are presented, U-tube steam generators (UTSGs) and once-through steam generators (OTSGs).

***4.2.2.1 U-Tube Steam Generator Nodalization.*** Standard nodalization for one of the primary coolant loops is shown in Figure 4-1. Pipe 408 represents the many thousands of steam generator tubes of a U-tube steam generator. Representing the steam generator tube primaries with an 8-cell pipe component is a nodalization scheme that compromises between calculational fidelity and expense. This scheme has proven is generally useful, however the modeler should individually consider the nodalization requirements for the problem to be modeled. The tube nodalization scheme shown may not be sufficiently detailed to model phenomena associated with reflux cooling and greatly reduced secondary-side levels. Branch 410 represents the steam generator outlet plenum. Modeling of the steam generator secondary region is described in Section 4.2.3.

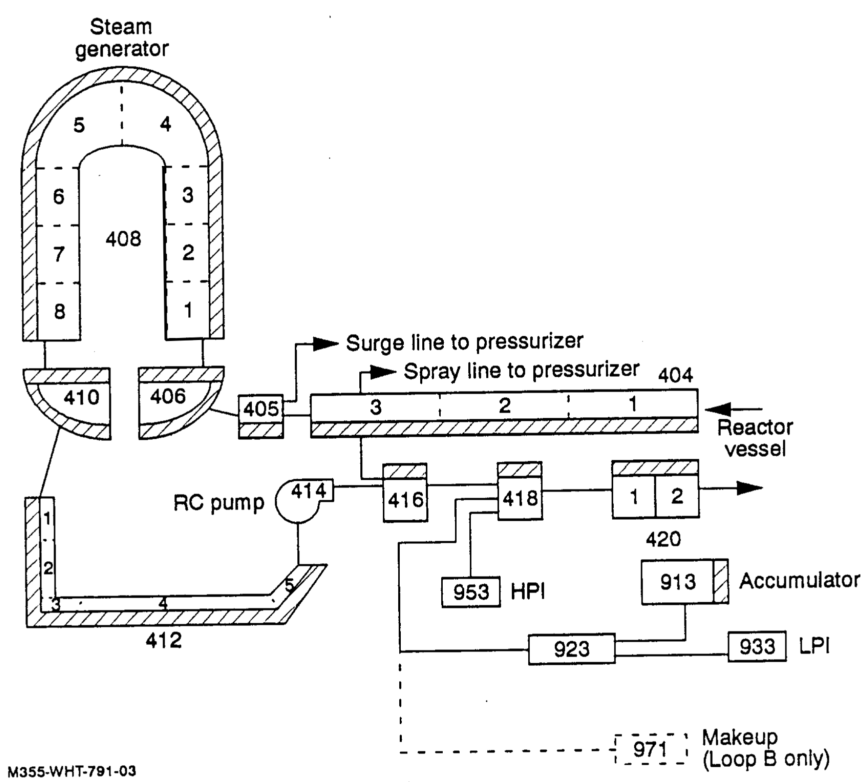


**Figure 4-1.** Nodalization of primary coolant loops (Loop C shown).

Heat structures are employed to model the hot and cold leg piping walls, the steam generator plena heads, the plena separation plate, the tubesheet, and the steam generator tubes.

***4.2.2.2 Once-Through Steam Generators.*** The OTSG is a counterflow heat exchanger that employs straight tubes. The standard OTSG nodalization is shown in Figure 4-2. Components 116 and 125, represent the OTSG inlet and outlet plena, respectively. Single-sided heat structures represent the significant metal structures (such as the steam generator heads and the tubesheets). Reactor coolant flows downward through the insides of the tubes; 8-cell pipes 120 and 121 represent the tube primaries. Pipe 120 represents 90% of the OTSG tubes, pipe 121 represents the other 10% (the reason for separating the tubes in this manner is discussed below). Two-sided heat structures model the tube walls.

On the secondary side, the downcomer region is modeled with 4-cell pipe 305. Main feedwater enters the downcomer at the upper end of this component. Single-sided heat structures represent the steam generator shell and the vertical baffle that separates the boiler and downcomer regions. Branch 306 represents the region at the lower tubesheet, where the flow changes direction from downward to upward.

The boiler region is separated into two parallel flow paths, representing 90% and 10% of the flow area. The paths are connected by crossflow junctions. Components 310 through 323 represent the 90% region while components 360 through 372 represent the 10% region. The split boiler region model is recommended to simulate phenomena during periods of emergency feedwater injection. This injection enters the boiler around the circumference of the boiler, near the upper tubesheet (junction 854 in the model) and is directed radially inward, into the tube bundle. Because the OTSG employs over 15,000 tubes, the emergency feedwater wets only a small portion of the tubes around the periphery of the tube bundle. As the emergency feedwater falls downward, it encounters the tube support plates (there are 17 in the OTSG) that tend to spread the injection flow further into the tube bundle. The split boiler nodalization represents a compromise modeling scheme for simulating this behavior. An initial 10% bundle penetration is expected, and the crossflow connections to the 90% region allow simulation of the inward spreading.

At the top of the boiler region, flows from the parallel boiler channels are combined in branch 325 before exiting the steam generator through a steam annulus, modeled with components 330 and 340.

Modeling the behavior of an OTSG is perhaps the most difficult of nuclear thermal-hydraulic system code problems encountered. The difficulty arises for two reasons. First, a complete spectrum of heat transfer phenomena is experienced between the tube wall and the secondary fluid. At the bottom of the tubes, heat transfer is to subcooled liquid. As the flow progresses up the tubes, the liquid is then saturated and boiled away. To preheat the feedwater, a portion of the steam flow is bled into the downcomer through an aspirator near mid-boiler (modeled with the junction between components 365 and 305 in Figure 4-2). Further up the tubes, any remaining droplets are vaporized and the steam is significantly superheated. Second, the OTSG heat removal rate is very sensitive to the secondary-side liquid level. As the level increases, more of the tube surface area experiences effective heat transfer (e.g., boiling) rather than ineffective heat transfer (e.g., convection to steam). Moreover, the sensitivity of OTSG heat removal to level is present during normal operation, while for UTSGs this is a concern only during accidents that involve an extreme depletion of secondary liquid.

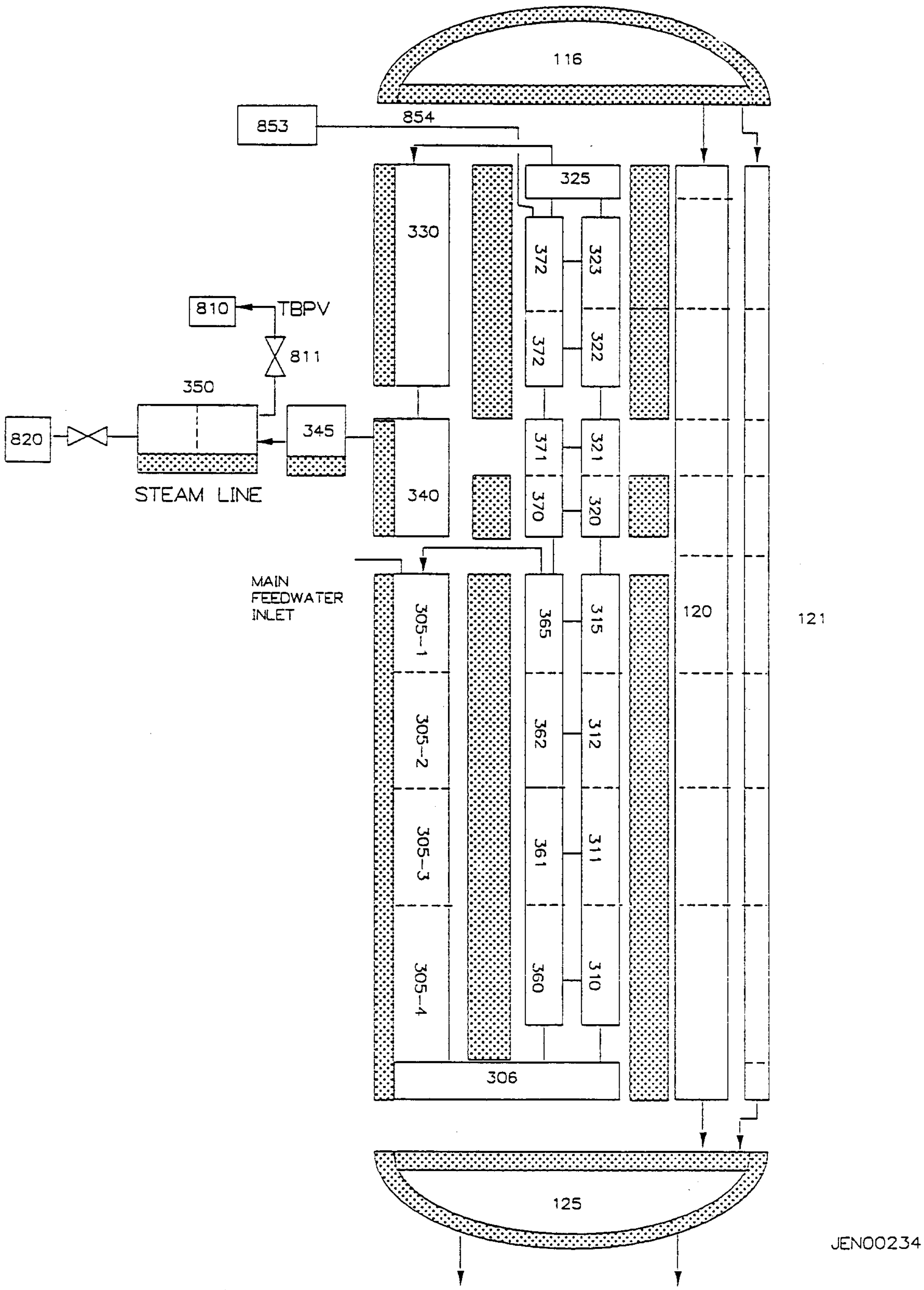


**Figure 4-2.** Example of once-through steam generator (OTSG) nodalization.

The OTSG steam generator nodalization shown in Figure 4-2 has proven adequate for simulating normal operation. The difficulty in obtaining a satisfactory OTSG simulation described above is partly nodalization dependent. Nodalization is by nature discrete, and this causes the steam generator heat removal in the model to be even more sensitive to the secondary level than in the prototype. In the model, as the level moves across cell boundaries, discrete jumps in overall heat transfer are encountered. These changes often cause the model to become unstable, oscillating between two solutions at two different secondary levels. Moving to finer axial noding may remedy the oscillation, however the proximity of the liquid level to cell boundaries often is more important than cell size.

### 4.2.3 Steam Generator Secondaries

Standard nodalization for a U-tube steam generator secondary is shown in Figure 4-3. In the secondary region, main feedwater enters the steam generator downcomer annulus at branch 258 where it is combined with the recirculation liquid flow returning from the separator (component 278) through downcomer annulus branch 254. The combined flow descends through the downcomer (annulus 262) and enters the boiler (pipe 266). Note that the axial nodalization was made consistent between the tube primary, boiler, and downcomer regions. The use of four axial hydrodynamic cells in the boiler region has proven generally useful. However, finer nodalization of the boiler region may be needed for simulating phenomena associated with reflux cooling mode and significantly depleted steam generator secondary inventory. The user is advised to carefully consider the nodalization needs for a particular application. Overall steam generator performance is dependent on correctly simulating the recirculation ratio (the boiler flow rate divided by the feedwater/steam flow rate) because it controls the heat transfer process on the outside of the tubes. The flow losses associated with the horizontal baffles in the tube bundle region often are not well-characterized. Therefore, if a satisfactory initial agreement with the desired recirculation ratio is not attained, adjustment of input form losses in the boiler may be justified.

The two-phase mixture exiting the boiler region flows through the mid-steam generator regions (branches 270 and 274) before entering the separator (branch 278). The separator model is idealized and includes three modes of operation that are determined by the separator void fraction. The void fractions defining these modes are input by the user. At low void fractions, the separator model reverts to a normal branch component, allowing carryover of liquid into the steam dome (branch 282). At high void fractions, the separator also reverts to a normal branch component, allowing carryunder of steam through the liquid return path into the downcomer. At intermediate void fractions, an idealized separation process is calculated: all liquid is returned to the downcomer and all vapor is passed to the steam dome.

The modeler should carefully consider the elevation chosen to locate the separator. In the steam generator model, separation will take place based on the void fraction in the separator volume, whose lower and upper elevations are user-specified. In the actual plant, separation is accomplished in two stages (swirl-vane separators and steam dryers) that reside at two different elevations. Therefore, the model is at best a compromise of the actual separation processes. The selections of separator elevation span and void limits determine when recirculation is interrupted as the secondary mixture levels decline. Note that these levels decline significantly when a steam generator’s heat load is reduced, such as following a reactor trip. The levels also decline significantly during transients where the secondary inventory is depleted, such as

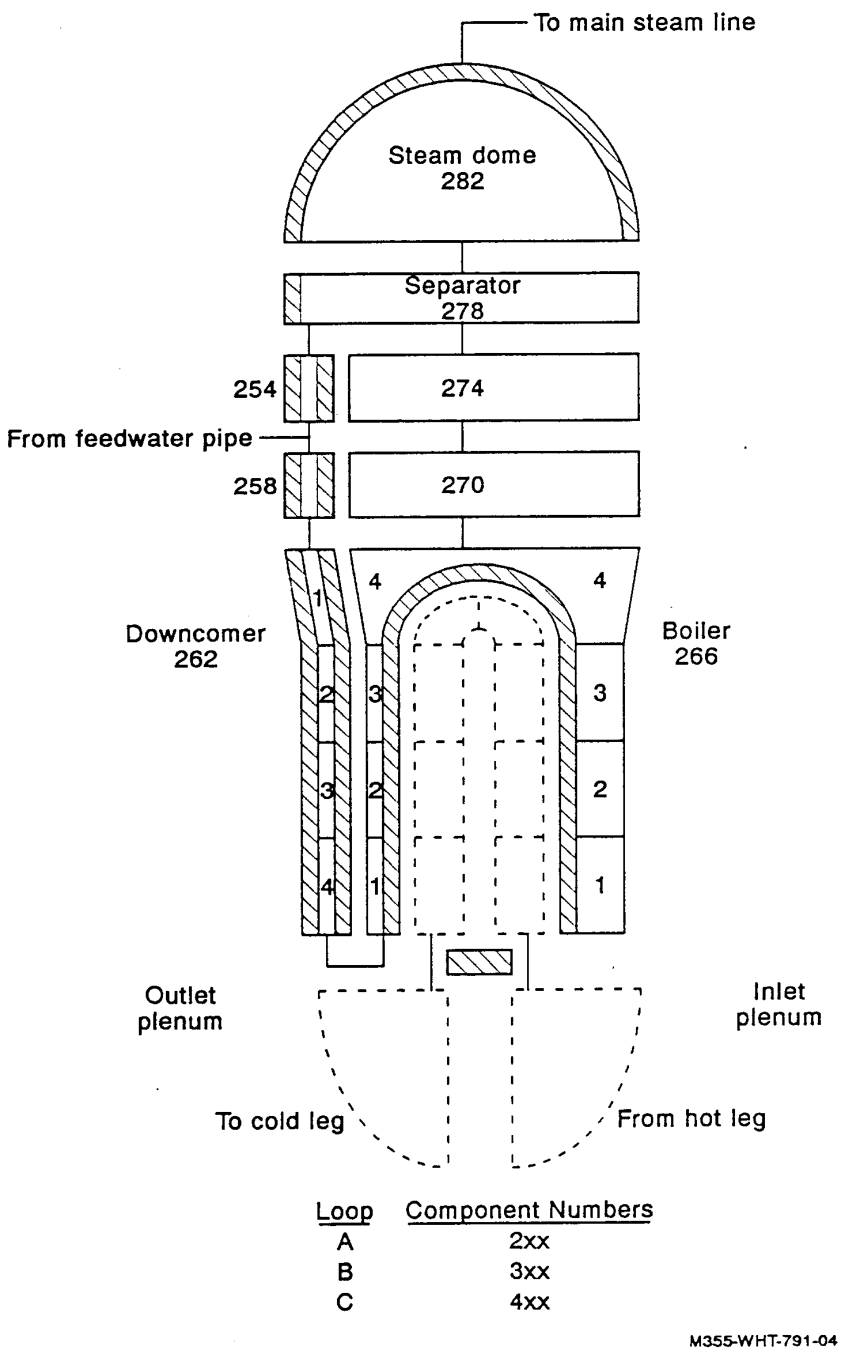


**Figure 4-3.** Nodalization of secondary side of steam generators.

during a secondary side LOCA.

Heat structures are employed in the model to represent the steam generator tubes, the cylindrical shell and spherical head, the cylindrical baffle separating the boiler and downcomer regions, and the internals of the separator and steam dome regions.

It often is difficult to obtain a satisfactory agreement with steam generator full-power conditions. The difficulty arises because the heat transfer coefficient calculated on the outside surface of the steam generator tubes is based on general vertical-pipe correlations rather than correlations that account for the swirling flows present within the tube bundle region. The swirling flow pattern results because horizontal baffles in the boiler direct the flow back and forth across the tube bundle instead of allowing the flow to proceed axially (vertically upward) through the boiler. The effect of this discrepancy is that tube heat transfer is understated by the code, resulting in excessively high calculated primary coolant temperatures (the temperatures increase until the core heat is driven across the tubes). Since the source of the calculated error is understood (i.e., a general heat transfer correlation is not appropriate for this application), it is recommended that the modeler "adjust" the heat transfer on the outside of the tubes to remedy the discrepancy.

The recommended adjustment is to reduce the input heated equivalent diameter on the heat structure cards for the outer tube surface. It is recommended that instead of using the boiler region hydraulic diameter as the heated diameter that the minimum tube-to-tube spacing (the distance from the outside of a tube to the outside of its neighbor) be used. If the modeler decides not to follow this recommendation, it will be necessary to compromise an important parameter (such as using a lower secondary pressure, higher primary temperature, or lower feedwater temperature) to simulate full-power steam generator operation.

### 4.2.4 Primary Coolant Pump

A typical nodalization for the primary coolant pumps is again shown in Figure 4-1. Pipe 412 represents the pump suction cold leg. To ensure proper simulation of behavior in the loop seal region, cell 4 of this pipe is input as horizontal. This orientation allows the formation of horizontally stratified flows at the bottom of the loop seal. It is recommended that at least one horizontal cell be used for simulating loop seal phenomena. Cells 1, 2, 3, and 5 of pipe 412 provide sufficient vertically-oriented calculational cells for simulating the formation of liquid levels in the loop seal region and for simulating countercurrent flow limiting phenomena.

The pump discharge cold leg is modeled with branches 416 and 418 and pipe 420. This nodalization scheme has proven suitable for simulating horizontal stratification of fluid within the cold legs during loss-of-coolant accidents. The nodalization also provides for proper simulation of the fluid temperature distribution in the region; the junction between the branches is located such that the ECC injection site is correctly modeled. The user should remember that SCDAP/RELAP5-3D© provides a one-dimensional representation of the flow and therefore is not capable of resolving thermal stratification of warm and cold liquids within the same pipe. Therefore, although the model may observe the bulk movement of cold ECC liquid toward the core, it is not capable of observing a stream of cold liquid residing in the bottom of the horizontal pipe. The high and low pressure ECC functions are modeled with pairs of time-dependent volumes and junctions. The ECC fluid injection temperature is specified by the time-dependent volume while the injection flow rate is specified as a function of the cold leg pressure by the time-dependent junction. This method allows simulating the head/flow characteristics of the centrifugal ECC pumps. A SCDAP/RELAP5-3D© accumulator component is used to simulate the injection behavior of the nitrogen-charged accumulators. This lumped-parameter component model mechanistically represents the tank and surge pipe hydrodynamics, heat transfer from tank wall and water surface, water surface vaporization to the gas dome, and gas dome condensation.

### 4.2.5 Pressurizer

Standard INEL nodalization for the pressurizer and its associated systems is shown in Figure 4-4. The pressurizer upper head is modeled with branch 340 and the pressurizer cylindrical body and lower head are modeled with 7-cell pipe 341. Generally, good agreement with experimental and plant data has been attained for slow and fast pressurizer insurges and outsurges with this nodalization. The surge line is modeled with 3-cell pipe 343.

The functions of the two power-operated relief valves (PORVs) are lumped into valve 344 and those of the three code safety valves are lumped into valve 346. The valves open in response to a significant primary coolant system overpressure. Operation of these valves, including their hysteresis effects, is simulated using methods described in Reference 12. The pressurizer spray system is modeled with single-volumes 335, 337, and 339, and valves 336 and 338. The spray valves open in response to a mild primary coolant system overpressurization. Operation of these valves is simulated using logic similar to the PORV and code safety valves. The flow area of all valves is that necessary for delivering the rated flow capacity at the rated upstream pressure.

Heat structures are used to represent the cylindrical pressurizer shell and its spherical lower and upper heads, and the pressurizer surge line pipe wall. Heat structures are also used to simulate operation of the pressurizer heaters. Heater power is increased in response to an underpressurization of the primary coolant system pressure and is terminated if a low pressurizer level is sensed.

## 4.3 Break Nodalization

### 4.3.1 LOCA Modeling

A common code application is simulating a loss-of-coolant accident (LOCA) involving the full or partial rupture of a coolant pipe within an air-filled containment. These applications may involve experimental facility or full-scale plant LOCA simulations.

The need to adequately measure the break flow in an experimental facility usually dictates a complex experimental break geometry to provide clearance for instrumentation. The experimental facility break design often involves a side pipe leading from the broken pipe to a break orifice and valve. This complex design is best modeled in detail (i.e., the geometry upstream and downstream of the break should be

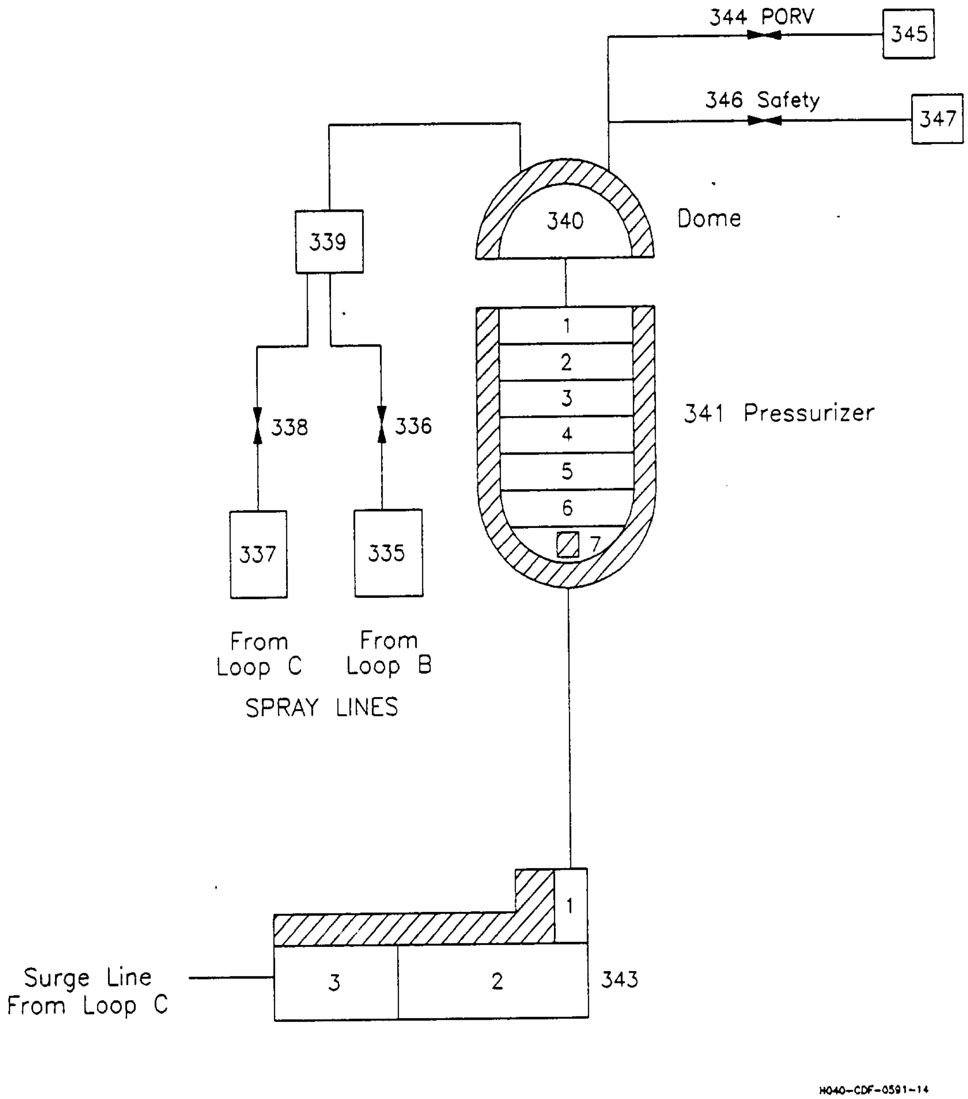


**Figure 4-4.** Nodalization of pressurizer.

modeled directly). Courant limiting considerations will be important in this application because the fluid velocities in the pipe leading to the break will be large. In most analyses of experimental facility LOCAs, benchmarking the break flow path has been necessary to compensate for uncertainties in the break path resistance and the code break flow models. The benchmarking process consists of using experimental data that characterize the break resistance to adjust the model flow losses for an adequate comparison between measured and calculated break flow. The adjustment is typically accomplished by adjusting the discharge coefficients on the break junction.

For full-scale plant applications, the break modeling process typically is more straightforward because the break geometry is simpler. Common LOCA applications for full-scale plants include the opening of circular breaks on the top, side, or bottom of a coolant pipe and the double-ended break of a coolant pipe. For full-scale plants, breaks typically are assumed to open instantly. Figure 4-5 shows a recommended nodalization for modeling small and double-ended breaks in a coolant pipe. In both applications, the broken pipe is simulated with volumes 110 and 120.

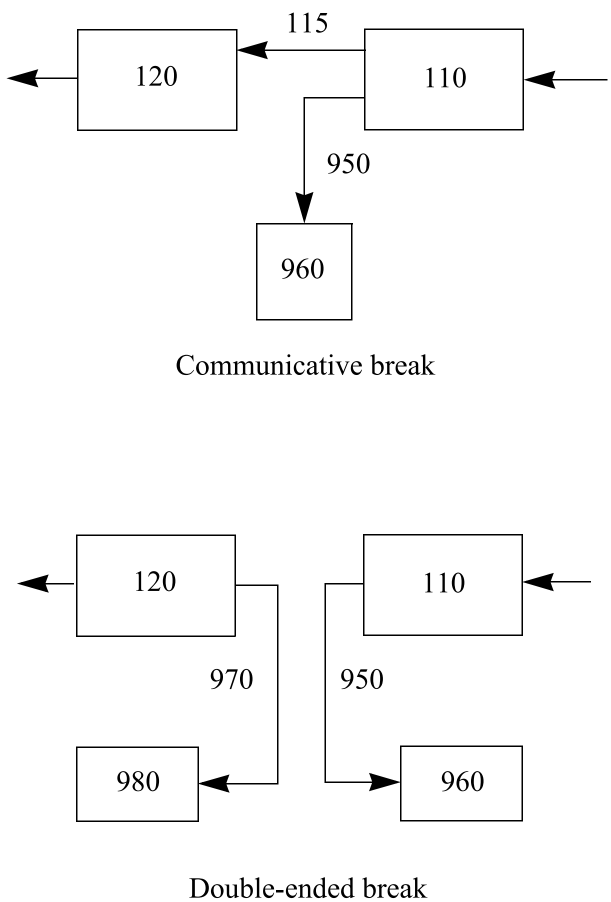


**Figure 4-5.** Coolant system break modeling.

The small communicative break is simulated by adding single-junction 950 and TMDPVOL 960 to the existing hot leg pipe model. The term “communicative” implies a portion of the normal flow through the pipe continues after the break is opened. Note that the break components may be installed on restart, at the time of break opening, by including components 950 and 960 in the input stream. Break junction 950 should employ the abrupt area change option, simulating the combined flow losses associated with the sharp-edged area reduction from the pipe to the break plane and the sharp-edged expansion from the break plane to the containment. Junction 950 should employ the choking option and be initialized at a zero flow condition. The junction control flags provide the capability to locate the break on the top, side, or bottom of the pipe.

TMDPVOL 960 simulates the containment into which the break discharges; this implies the containment state is a boundary condition in the calculation. Frequently, a constant-pressure containment assumption is used. If the containment pressure response is known (e.g., as a function of the integrated break flow), then that response may be included in the simulation. For the double-ended break the nodalization includes two break junctions and two TMDPVOLs, as shown in Figure 4-5. Note that two TMDPVOLs are needed because no more than one junction may be attached to a TMDPVOL. As for the small break, the break junctions should employ the abrupt area change and choking options. Care should be used when specifying the initial break conditions. In the example shown, the initial mass flow rate for junction 950 should be positive at the same rate as at the inlet to volume 110; the initial mass flow for junction 970 should be negative and of the same magnitude.

In the above examples, the breaks also could have been implemented by including trip valve components at the break junctions in the original model rather than by adding them on restart. The valves would then be tripped open at the time of the break. Using this technique, the breaks may be opened at any time, not just at a restart point.

The containment condition specification is more important in some applications than in others. For small break applications, the primary coolant system depressurization typically is small, the pressure drop across the break remains large, and the break flow remains both choked and positive (into the containment). The containment conditions specified in this situation are not particularly significant to the simulation. The problem is only moderately sensitive to the containment pressure and is insensitive to its gas species. However, for large breaks, transitions between choked- and friction-dominated flow, and intermittent reverse flow from the containment are likely. In this case, it is important to adequately specify the containment conditions.

For some problems where the response of the containment is particularly important, it may be possible for an approximation of the containment behavior to be included as a part of the model. This can be accomplished by modeling the containment and the actual containment mass and heat balances.

As a final note, the analyst should appreciate that critical break flow simulation represents an area of significant uncertainty. For some problems, this uncertainty may be a controlling factor for the outcome of the simulation. It is therefore recommended that care be taken to independently check code-calculated break flow results either against experimental data in similar geometries or against standard critical flow correlations.

A recommended procedure for correctly specifying the break area and discharge coefficient is linked to the break scenario, the break plane geometry, and whether any data exists for that geometry. Assuming a discharge coefficient of 1.0 is valid, the following generalities are known concerning the SCDAP/RELAP5-3D© critical flow model:

- For subcooled conditions, the SCDAP/RELAP5-3D©-calculated flow is too large. Often, it is found that a discharge coefficient of about 0.8 is needed to predict break flow in representative geometries containing break nozzles with length-to-diameter ratios less than 1.0.

- For low-quality saturated conditions, SCDAP/RELAP5-3D©-calculated mass flow rates are too low, often by as much as 20%, even when a discharge coefficient of 1.0 is used.

- Higher-quality saturated conditions at the break plane, such as are approximated by the homogeneous equilibrium model, are well-simulated with SCDAP/RELAP5-3D©.

### 4.3.2 Surge Line Modeling

One of the transient phenomena which is unique to severe accident analysis is failure of the pressurizer surge line. Surge line break modelling differs from most breaks because of the fact that the timing of the failure is not a boundary condition, but is calculated by the SCDAP/RELAP5-3D© code. Modelling of the failure of a surge line can be performed in one of the following two methods.

METHOD 1:

- Model the surge line walls with RELAP5 heat structures.

- Identify surge line heat structures for the creep rupture calculation, on Cards 21000110 and 21000000.

- Specify the 'DCREPH' variable on 208 cards to allow it's use with a logical trip.

- Specify a logical trip to be driven 'true' when any 'DCREPH' variables indicates rupture.

- Model the surge line failure with a valve from the surge line to containment. This valve could be modeled as the communicative break shown in Figure 4-5, with the valve numbered 950. The valve should be initially closed, and open when the trip specified in step 4 is driven 'true'.

METHOD 2:

- Model the surge line walls with RELAP5 heat structures.

- Identify surge line heat structures for the creep rupture calculation on Cards 21000110 and 21000000.

- Perform a calculation to identify the time of the first creep rupture.

- Restart the calculation with a break being defined for the time of creep rupture.

The flow area of the valve which models the surge line rupture is probably plant and transient specific. Creep rupture failure experiments show creep rupture failures to involve longitudinal cracks that had opened to various degrees, from about 1/4 of the axial flow area to an area at least as large as the axial flow area. It should be noted that there is a wide scatter of experimental data in this area. In the model for surge line rupture for the Surry plant,[14] a rupture flow area equal to 1/3 of the pipe axial flow area was judged appropriate. This amounts to a valve diameter of approximately 1/2 of the surge line pipe.

# 5. PROBLEM CONTROL

Input, output, and auxiliary file names are identified on the command line using flags, as shown in Appendix B. All remaining control parameters are specified within the input deck as documented in Appendix A.

## 5.1 Problem Types and Options

SCDAP/RELAP5-3D© provides for four problem types: NEW, RESTART, PLOT, and STRIP. The first two are concerned with simulating hydrodynamic systems; NEW starts a simulation from input data describing the entire system; RESTART restarts a previously executed NEW or RESTART problem. PLOT and STRIP are output type runs using the restart-plot file written by NEW or RESTART problems. NEW and RESTART problems require an additional option to be selected, STDY-ST or TRANSNT.

A RESTART problem may restart from any restart record. A note indicating the restart number and record number is printed at the end of the major edit whenever a restart record is written. The restart number is equal to the number of attempted advancements and is the number to be used on Card 103 to identify the desired restart record. The record number is simply a count of the number of restart records written, with the restart record at time equal zero having record number zero. Quantities written in the restart-plot records by default are noted in the input data description. User-specified input can add additional quantities to the restart-plot records.

PLOT and STRIP are output-type runs. PLOT generates plots from data stored on the restart-plot file. The PLOT capability is not now operational but is still documented. The PLOT capability may be dropped from the code since NPA[6] and XMGR5,[15] an INEEL extension of XMGR[16] allow very general and high quality plots of SCDAP/RELAP5-3D© results and associated information. STRIP writes selected information from a restart-plot file onto a new file. The new file consists of records containing time and the user-selected variables in the order selected by the user. Data to be plotted or stripped are limited to that written in the plot records on the restart-plot file.

## 5.2 Time Step Control

Input data for time step control consist of one or more cards containing a time limit, minimum time step, requested (maximum) time step, control option, minor edit plot/frequency, major edit frequency, and restart frequency. The time limit must increase with increasing card numbers. The information on the first card is used until the problem time exceeds the card limit, then the next card is used, and so on. In restart problems, these cards may remain or may be totally replaced. Cards are skipped if necessary until the problem time at restart is properly positioned with regard to the time limit values.

Several time step control options are available. Transfer of information between the hydrodynamic and heat conduction advancements is explicit, and the advancement routines are coded so that each advancement can use a different time step. Although not now used, each heat structure can also use its own time step. The time step control option is represented by a number between 0 and 15 that can be thought of as a four bit number. Entering zero (no bits set) attempts to advance both the hydrodynamic and heat conduction advancements at the requested time step. However, the hydrodynamic time step will be reduced such that the Courant limit is satisfied. If out of range water property conditions are encountered, the advancement will be retried with reduced time steps. The problem will be terminated if the time step must be reduced beyond the minimum time step. Each time step reduction halves the previously attempted time step. At the beginning of an advancement for a requested time step, a step counter is set to one. Whenever a reduction occurs, the step counter is doubled. When a successful advancement occurs, the step counter is reduced by one. When the step counter is decremented to 0, the problem has been advanced over one requested time step. Doubling of the time step is allowed only when the step counter is even, and the step counter is halved when the time step is doubled. With no bits set, the time step is doubled whenever possible. At the completion of advancements over a requested time step, the next requested advancement is obtained and may be different from the previous requested time step if data from the next time step control card are used. If necessary, the new requested time step is reduced by halving until the new actual time step is < 1.5 times the last successful time step.

Setting bit one (entering 1, 3, 5, 7, 9, 11, 13, or 15) includes the features described for entering zero and in addition uses the halving and doubling procedures to maintain an estimate (mass error) of hydrodynamic truncation error within program defined limits. If an acceptable error is not reached and the next reduction would lead to a time step below the minimum time step, the advancement is accepted. The first 100 such occurrences are noted in the output.

If the second bit is set (entering 2, 3, 6, 7, 10, 11, 14, or 15), the heat structure time step will be the same as the hydrodynamic time step. The time step control for the hydrodynamics is determined by the status of the first bit as described above, and both the heat conduction and hydrodynamic advancements are repeated when a time step reduction occurs.

If the third bit is set (entering 4, 5, 6, 7, 12, 13, 14, or 15), the heat transfer will use the maximum time step and the hydrodynamics will use the partially implicit hydrodynamic and heat slab coupling. The time step control for hydrodynamics is determined by the status of the first bit, as described above.

If the fourth bit is set (entering 8, 9, 10, 11, 12, 13, 14, or 15), the hydrodynamics will use the nearly-implicit hydrodynamic numerical scheme. The time step can be as large as five times the Courant limit for the TRANSNT option and ten times the Courant limit for the STDY-ST option. The time step control for hydrodynamics is determined by the status of the first bit, as described above.

Note that combinations of the effects of setting of the individual bits are achieved by setting bits in combination. For example, entering five (setting bits three and one) results in the combined effects described above for bits three and one. Older versions of this code would convert 2 to 3 to maintain compatibility. This is no longer done.

Entering zero is not recommended except for special program testing situations. If bit one is set, care must be taken in selection of the requested time step. Individually, the hydrodynamic and heat conduction advancements are stable; the hydrodynamic time step is controlled to ensure stability, the heat conduction solution with constant thermal properties is stable for all time steps, and the change of thermal properties with temperature has not been a problem. The explicit coupling of the hydrodynamic volumes and heat structures through heat structure boundary conditions can be unstable, and excessive truncation error with large time steps can occur. This has been observed in test problems. Entering three usually eliminates the problem, but often with unnecessary calculations. Judicious use of this option during dryout and initial rewetting may be cost-effective. Most LOFT and Semiscale simulations have entered three for the entire problem.

The minor edit, major edit, and restart frequencies are based on the requested time step size. A frequency n means that the action is taken when a period of time equal to n requested time steps has elapsed. The edits and the restart record are written at time zero and at the specified frequencies up to the time limit on the time step control card. The maximum time step is reduced if needed, and the edits and restart record are forced at the time-limit value. Actions at the possibly new specified frequencies begin with the first advancement with a new time step control card. A restart forces a major and minor edit to be written, and a major edit forces a minor edit to be written. Plot information is written to the internal plot and restart-plot files whenever a minor edit is written. Note that minor edits are produced only if minor edit requests are entered; a plot file is written only if plot requests are entered; and plot and restart data are written on the restart-plot file only if the file is requested.

An option used for program testing can force a plot print, minor edit, major edit, or combinations of these to be written at each advancement. Care should be used, since considerable output can be generated.

Major edits forced by the program testing option or the last major edit of the problem terminated by approach to the job CPU limit may not coincide with the requested time step. When this occurs, a warning message is printed that states that not all quantities are advanced to the same time points.

The control option is a packed word containing a major edit select option, a debug output option, and the time step control. The major edit select option allows sections of major edits for the hydrodynamic volumes and junctions, heat structures, and statistics to be skipped. The debug output option forces any combination of plot, minor edits, or major edit output to be written at each successful advancement rather than at just the completion of advancement over a requested time step. All options can be changed with each time step control card.

## 5.3 Printed Output

A program version identification is printed at the beginning of printed output and the first page following the listing of input data.

### 5.3.1 Input Editing

Printed output for a problem begins with a list of card images, one per line, preceded by a sequence number. The sequence number is not the same as the card number on data cards. Notification messages are listed when data card replacement or deletion occurs. Punctuation errors, such as an alphabetic character in numeric fields, multiple signs, periods, etc., are noted by an error message; and a $ is printed under the card image indicating the column position of the error.

Input processing consists of three phases. The first phase simply reads and stores all the input data for a problem such that the data can later be retrieved by card number. Error checking is limited to punctuation checking, and erroneous data flagged during this phase nearly always causes additional diagnostics in later phases. The second phase does the initial processing of data. Input data are moved and expanded into dynamic arrays sized for the problem being solved, and default options are applied.

Processing and error checking is local to the data being processed. That is, when processing a single-junction component, no checking is performed regarding the existence of connected volumes. Similarly, hydrodynamic volumes connected to heat structure surfaces are not checked during processing of heat structure boundary data. At the end of this phase, all data cards should have been used. Unused cards are considered errors and are listed. Asterisks following the card number indicate that the card number was bad, an error was noted in the card image listing, and that the number is the sequence number rather than the card number. The third phase completes input processing and performs requested initialization. Once the second phase has been completed, data specifying linkages between various blocks of data can now be processed and checked. Examples of error checking are junction connections made to nonexisting volumes, heat structure surfaces connected to nonexisting hydrodynamic volumes, specified thermal properties, and power data not entered. Solution of steady-state heat conduction for initial temperature distribution in heat structures is an example of initialization.

Depending on the type of data, input is edited in only one of the last two edits or in both of them. Error diagnostics can be issued during either phase, even if no editing for the erroneous data is done in a phase. When an error is detected, possible corrective actions are disregarding the data, which usually leads to other diagnostics; inserting benign data; or marking data as being entered but useless for further processing. These actions are taken so that (other than errors on problem type and options) input processing continues despite severe errors. Regardless of errors, all data are given preliminary checking. Severe errors can limit cross-checking. Correcting input errors diagnosed in a submittal may lead to other diagnostics in a subsequent submittal, as elimination of errors allow more detailed checking. Except for exceeding requested computer time and printed output limits, any abnormal termination is considered a programming error and even exceeding computer time limits is prevented during transient execution. The final message of input processing indicates successful input processing or that the problem is being terminated because of input errors.

### 5.3.2 Major Edits

Major edits are an editing of most of the key quantities being advanced in time. The amount of output depends on the input deck and output options chosen by the code user. Output includes a time step summary, trip information, reactor kinetics information, one to four sections of hydrodynamic volume information, hydrodynamic volume time step control information, one or two sections of hydrodynamic junction information, metal-water reaction information, heat structure/heat transfer information, heat structure temperatures, reflood information, reflood surface temperatures, cladding rupture information, control variable information, and generator pump, turbine, and accumulator information. Major edits are quite lengthy, and care should be used in selecting print frequencies. Some sections of major edits can be bypassed through input data on time step control cards.

### 5.3.3 Minor Edits

Minor edits are condensed edits of user-specified quantities. The frequency of minor edits is user-specified and may be different from the major edit frequency. The selected quantities are held until 50 time values are stored. The minor edit information is then printed, 50 time values on a page, nine of the selected quantities per page, with time printed in the left most column on each page. Minor edits can print selected quantities at frequent intervals using much less paper than major edits. Appendix A indicates how to request minor edits and what the user-specified quantities represent.

## 5.4 Edits of SCDAP Heat Structures

The values of variables that describe the state of SCDAP heat structures are printed at the same times that major edits are performed for the RELAP5 calculations. The printout describes the temperature, deformation, and oxidation of fuel rods and control rods and the fission product release from fuel rods. The state of each SCDAP heat structure is printed in the order of its number identifier. In other words, Component 1 is printed first, then Component 2, and so forth.

### 5.4.1 Temperature Distribution

The first section of printout shows the temperature distribution of the SCDAP heat structure with a component identification number of 1. The fuel centerline and cladding surface temperatures are printed for each axial node. The temperatures have the units of degrees Kelvin. The elevation of each axial node in units of meters is also printed. The radial temperature distribution is shown at the elevation of the midplane of the SCDAP heat structure, and the temperature at each radial node is printed for the midplane elevation.

### 5.4.2 Cladding Radius

The next section of printout shows the inner and outer radii of the fuel rod cladding. This printout indicates the extent of cladding ballooning. The inner and outer radii are printed for each axial node. The left most radius that is printed applies to the lowest axial node and the right most radius applies to the highest axial node.

### 5.4.3 Cladding Oxidation

The next ten lines of numbers that are printed show the results of calculations of cladding oxidation. The oxidation variables are printed for each axial node, with the lowest axial node printed left most and the top axial node printed right most. The extent of the cladding oxidation is displayed by the line printing the fraction of cladding oxidation at each node. If the value of the fraction of cladding oxidation is equal to one, then the cladding is entirely a shell of $ZrO_2$.

### 5.4.4 Meltdown

The next eleven lines of numbers show the extent of fuel rod liquefaction and meltdown. The extent to which liquefied cladding has dissolved the outer part of fuel pellets is shown by the line printing the inner radius of annulus of dissolved $UO_2$. If no fuel dissolution has occurred, then the printed value of the inner radius is equal to the outer radius of the fuel pellets. The next several lines of printout show the relocation of fuel and cladding. Unless fuel has slumped below the fuel rod, the sum of the mass of $UO_2$ solidified at each axial node per rod equals the sum of the mass of $UO_2$ removed from each axial node per rod. The same rule holds for cladding. If the mass of zirconium removed from an axial node is greater than zero, then all the metallic zirconium has slumped from that node and oxidation no longer occurs at then node.

### 5.4.5 Fission Product and Aerosol Release

The next several lines of printout show the results of calculations of fission product and aerosol releases. The fission product inventory within the fuel is shown by the printout of matrix of numbers. The left most column of numbers applies to the lowest axial node (axial Node 1), and the right most applies to the highest axial node. Each row of the matrix shows the mass in units of kilograms per axial node per fuel rod of a certain species of fission product. The first row shows the inventory of xenon, the second row krypton, the third row cesium, the fourth row iodine, and the fifth row is the inventory of tellurium as calculated by the PARAGRASS[3] fission gas release model.

The balance of the rows show the inventory of aerosols for which the initial masses are input by the code user and for which the release is calculated by the CORSOR model.[17] The sixth row shows the retained mass of zirconium. If no aerosol release of zirconium has been calculated by the CORSOR model, then the mass of zirconium will equal the user input mass of zirconium per axial node. Similarly, the seventh row shows the inventory per axial node per rod for iron, the ninth row ruthenium, the tenth row a special isotope of zirconium, the eleventh row barium, the twelfth row strontium, the thirteenth row tellurium, the fourteenth row silver, the fifteenth row a special isotope of cesium, and the sixteenth row a special isotope of iodine.

The next line of numbers shows the inventory of fission products in the fuel cladding gap. The species are printed in the same order as for the printout of the fuel inventory. The left most species is xenon, the second left most species is krypton, and so forth. In addition, the mass of helium in the gap is printed as the seventeenth number.

The next line of numbers shows the cumulative release of fission products to the coolant. The mass is units of kilograms per rod is shown for each species. The species are printed in the same order as for the printout of the fuel inventory. In addition, the cumulative release of helium and hydrogen are shown as the seventeenth and eighteenth numbers respectively.

The code user can also obtain cumulative release of fission products to the coolant by subtracting the current inventory from the initial inventory. The difference in initial and current inventories is the amount released to the coolant in the case that the cladding has failed. If the cladding has not failed, then the difference is the amount released to the fuel cladding gap.

### 5.4.6 Cladding Ballooning and Rupture

The next three lines of numbers show the results of the cladding ballooning model. The first line shows the axial node at which the maximum amount of cladding ballooning is occurring. If the cladding has ruptured, it shows the axial node at which rupture occurred. The next line shows the cladding hoop strain at each axial node. The next line shows the pressure of gases in the fuel cladding gap. If the cladding has ruptured, the gas pressure is equal to the coolant pressure at that location.

### 5.4.7 Fuel Rod Power

The next three lines of numbers show the fuel rod heat generation rate. The first line shows the total heat generation rate (sum of prompt fission power, fission product decay heat, and actinide product decay heat) in units of W/m at each axial node. The next line of numbers is redundant data that are to be ignored by the code user. The third line shows the axially averaged linear heat generation rate.

The remaining lines of printout for the component are redundant and should be ignored by the code user.

## 5.5 Edits of HTGR Structures

The calculated behavior of the core, vessel, and containment of a High Temperature Gas Reactor (HTGR) is displayed at each major edit. If the reactor design includes downcomers and upcomers for the cooling of the reactor vessel by natural circulation with air from the atmosphere, each major edit also displays the calculated behavior of these structures. The display of the behavior calculated for these structures is placed immediately after the display of the behavior calculated for the fluids represented by RELAP5 control volumes. The display of calculated HTGR behavior begins with the line "Behavior of High Temperature Gas Reactor, time=". The next line shows the calculated total heat generation in the reactor due to fission and decay heat. The next line shows the total heat generation in the reactor core due to oxidation of the graphite in the reactor core. The minimum and maximum temperatures in fueled part of the reactor core are also displayed. The locations of the minimum and maximum temperatures are also displayed.

Several tables are next displayed that show the behavior calculated for the reactor core. First, a table is displayed that shows the radial and axial temperature distribution in the reactor core. Next, a table is displayed that shows the radial and axial distribution in the effective thermal conductivity of the reactor core. Next, a table is displayed showing the spatial distribution in heat capacity. The spatial distribution in fission and decay heat is presented next. If significant oxidation is occurring, tables showing the distribution of oxidation are presented. Last, the spatial distribution in heat removal by convection is presented.

The calculated behavior of the reactor vessel is displayed next. The vessel behavior display begins with the line "Description of state of reactor vessel." After this line, the maximum and minimum temperatures in the reactor vessel are displayed. The locations of the maximum and minimum temperatures are also shown. Next, a table is displayed showing the radial and axial temperature distribution in the rector vessel. Last, a table is displayed describing the calculated heat transfer by convection and radiation from the inner and outer surfaces of the reactor vessel.

If the reactor design includes an upcomer for the natural circulation of air from the atmosphere, the calculated behavior of this component is displayed next. The upcomer behavior display begins with the line "Description of state of channels for upward flow of air between reactor vessel and containment." A table describing the radial and axial temperature distribution in the upcomer is first displayed. Then, a table describing the heat transfer at the inner and outer surfaces of the upcomer is displayed. If the upcomer consists of individual channels arranged in a circle, a table is also displayed describing the convective heat transfer to the air inside these channels.

If the reactor design includes an downcomer for the natural circulation of air from the atmosphere, the calculated behavior of this component is displayed next. The downcomer behavior display begins with the line "Description of state of downcomer between upward flow air channels and containment." A table describing the radial and axial temperature distribution in the downcomer is first displayed. Then, a table describing the heat transfer at the inner and outer surfaces of the downcomer is displayed.

The calculated behavior of the reactor containment is next displayed. The containment behavior display begins with the line "Description of state of reactor containment". Then, the maximum and minimum temperatures in the containment are displayed. The locations of the maximum and minimum temperatures are also shown. Next, a table is displayed showing the radial and axial temperature distribution in the containment. If the outer surface of the containment is in contact with earth, the temperature distribution in the earth is also shown. Last, a table is displayed describing the calculated heat transfer by convection and radiation from the inner and outer surfaces of the containment. If the outer surface of the containment is in contact with earth, the heat transfer for the outer surface displays the adiabatic boundary condition applied to the outer region of the earth.

## 5.6 Transient Termination

The user may optionally specify one or two trips to terminate a problem. Normal termination is from one of these trips or the advancement reaching the final time on the last time step control card. Minor and major edits are printed and a restart record is written at termination. Since trips can be redefined and new time step cards can be entered at restart, the problem can be restarted and continued.

Transient termination can also occur based on two tests on the CPU time remaining for the job. One test terminates if the remaining CPU time at the completion of a requested time step is less than an input quantity. The second test is similar, but the comparison is to a second input quantity and is made after every time advancement. The input quantity for the first test is larger than for the second test because the preferred termination is at the completion of a requested time step. In either case, the termination can be restarted.

Failure terminations can occur from several sources, including hydrodynamic solution outside the range of water property subroutines, heat structure temperatures outside of thermal property tables or functions, and attempting to access an omitted pump curve. Attempting to restart at the point of failure or at an earlier time without some change in the problem input will only cause another failure. Problem changes at restart may allow the problem to be successfully restarted. Requested plots are generated after a failure termination.

### 5.6.1 Problem Changes at Restart

The most common use of the restart option is simply to continue a problem after a normal termination. If the problem terminated because of approaching the CPU time limit, the problem can be restarted with no changes to information obtained from the restart file. If the problem stopped because the advancement time reaching the time end on the last time step card, new time cards must be entered. If the problem was terminated by a trip, the trip causing the termination must be redefined to allow the problem to continue. Thus, the code must provide for some input changes for even a basic restart capability.

The ability to modify the simulated system at restart is a desirable feature. The primary need for this feature is to provide for a transition from a steady-state condition to a transient condition. In many cases, simple trips can activate valves that initiate the transient. Where trips are not suitable, the capability to redefine the problem at restart can save effort in manually transcribing quantities from the output of one simulation to the input of another. One example of a problem change between steady-state and transient is the use of a liquid filled, time-dependent volume in place of the vapor region of a pressurizer during steady-state. The time-dependent volume provides the pressurizer pressure and supplies or absorbs water from the primary system as needed. The time-dependent volume is replaced by the vapor volumes at initiation of the transient. This technique avoids modeling the control system that maintains liquid level and temperature during steady-state calculations when they are not needed in the transient.

Another reason for a problem change capability is to reduce the cost of simulating different courses of action at some point in the transient. An example is a need to determine the different system responses when a safety system continues to operate or fails late in the simulation. One solution is to run two complete problems. An alternative is to run one problem normally and restart that problem at the appropriate time with a problem change for the second case.

The problem change capability could also be used to renodalize a problem for a certain phase of a transient. This has not been necessary or desirable for problems run at the INEEL. For this reason, techniques to automate the redistribution of mass, energy, and momentum when the number of volumes changes have not been provided.

The current status of allowed problem changes at restart in SCDAP/RELAP5-3D© are summarized below. In all instances, the problem definition is that obtained from the restart tape unless input data are entered for deletions, modifications, or additions. The problem defined after input changes must meet the same requirements as a new problem.

Time step control can be changed at restart. If time step cards are entered at restart, all previous time step cards are deleted. New cards need only define time step options from the point of restart to the end of the transient.

Minor edit and plot input data cards can be changed at restart. If any of the minor edit cards are entered, all previous cards are deleted. New cards must define all desired minor edit quantities. The plot request data cards are handled in the same manner.

Trip cards can be entered at restart. The user can specify that all previous trips be deleted and can then define new trips. The user can also specify that the previously defined trips remain but that specific trips be deleted, be reset to false, be redefined, or that new trips be added.

Existing hydrodynamic components can be deleted or changed, and new components can be added. An especially useful feature is that the tables in time-dependent volumes and junctions can be changed. If a component is changed, all of the cards for the component must be entered.

Control system components can be deleted, changed, or added.

Heat structures, general tables, and material properties can also be deleted, changed, or added. If these are changed, all of the cards for heat structures, general tables, and material properties must be entered.

Reactor kinetics can be added or deleted on restart. A complete set of reactor kinetics data must be input, i.e., individual sections of kinetics data may not be specified as replacement data.

In summary, many modeling features in SCDAP/RELAP5-3D© can be added, deleted, or changed at restart.

# 6. BENCHMARK PROBLEMS

A set of standard input decks are transmitted with each transmittal, which allow the code user to exercise the code as it is installed on their site, and compare results with results generated with the same input decks by the code developers. In the follow sections, the objective of each test problem will be identified, and the approach, boundary conditions, and success criterion will be described.

## 6.1 Boiloff Problem

The 'boiloff' problem is a recent addition to the suite of standard test decks, and is intended to test the interface between the heat transfer package and the severe accident models. The approach is to define two completely separate, but identical hydraulic systems. Each of these systems consist of a pipe, with eight volumes, and a time-dependent volume acting as inlet and outlet, as shown in Figure 6-1. These volumes allow the user to define inlet and outlet hydrodynamic conditions. This problem is initiated with the pipe filled with water, experiences a standard boiloff, and then undergoes super heated steam boundary conditions. A time-dependent junction in used to connect the source volume to the pipe so that flow conditions through the pipe may be specified as a function of time. Connected to each pipe are either a RELAP5 heat structure or a SCDAP fuel rod, experiencing the same power history. The intent is to provide identical boundary conditions for each type of structure, and then to examine the differences in the calculated behavior of the SCDAP and RELAP heat structures.

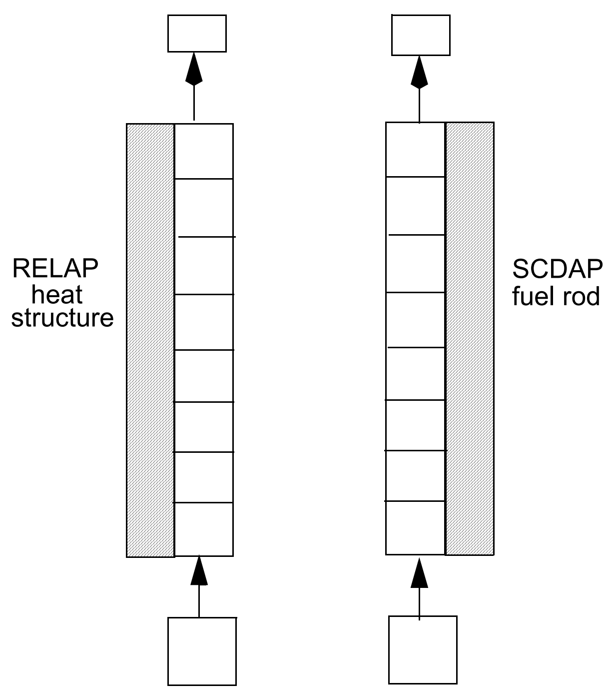


**Figure 6-1.** Boiloff nodalization diagram.

In the transmitted input deck, two control variables CNTRLVAR-110 and CNTRLVAR-111 may be compared to assess the effectiveness of the implementation. CNTRLVAR-110 sums the total heat which is added to the pipe by the RELAP heat structure and CNTRLVAR-111 sums the total heat which is added to the pipe by the SCDAP fuel rod. This problem is considered successful, if the control variables are similar, although there will be an increasing deviation as the cladding temperature increases, since the RELAP heat structure does not model cladding oxidation.

## 6.2 Simple Cheap Problem

Simple Cheap Problem #2 (SCP2) is intended to exercise the SCDAP fuel rod model by modeling the response of a 32 rod bundle through a very rapid transient to meltdown. The approach, just as in the previous problem, is to define a pipe with time-dependent volumes at each end, and a time-dependent junction at the source volume, as shown in Figure 6-2. The time-dependent volumes are used to specify inlet and outlet hydrodynamic conditions, and the time-dependent junction is used to specify time-dependent flow rates.

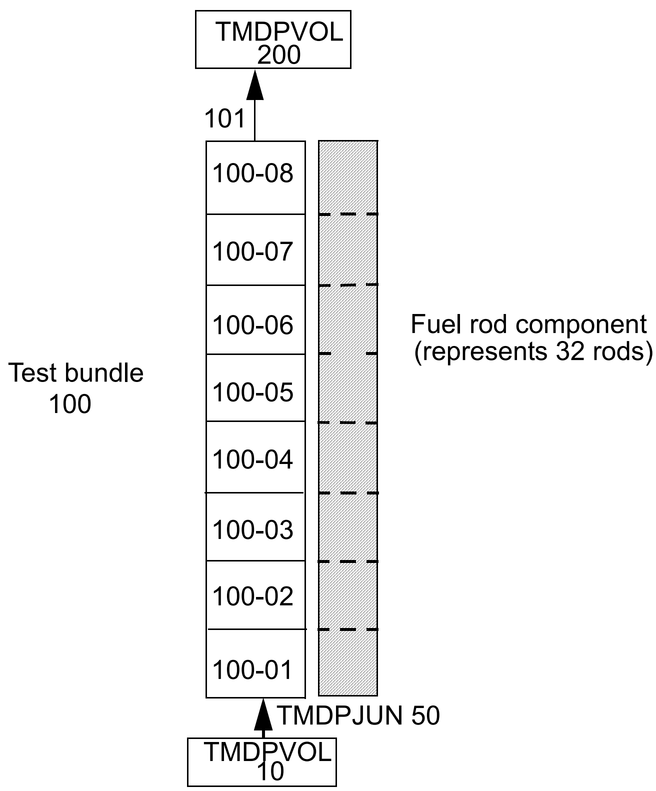


**Figure 6-2.** Nodalization diagram for Simple Cheap Problem #2.

In this problem, the pipe is initialized with steam and a steam flow comparable to that experienced during the PBF SFD 1-4 experiment is maintained. The fuel rod is expected to experience intense oxidation, cladding melting, and significant relocation. This problem is considered successful if it runs to completion without error, and without generating non-physical results.

### 6.2.1 Simple Cheap Problem Restart

An additional input deck is added to the suite, in order to allow a restart of the SCP2 run. This deck should perform a restart approximately 50 s prior to the end of SCP2, and run to the same end time. The problem is considered successful if identical results are obtained.

## 6.3 Simple Cheap Vessel Problem

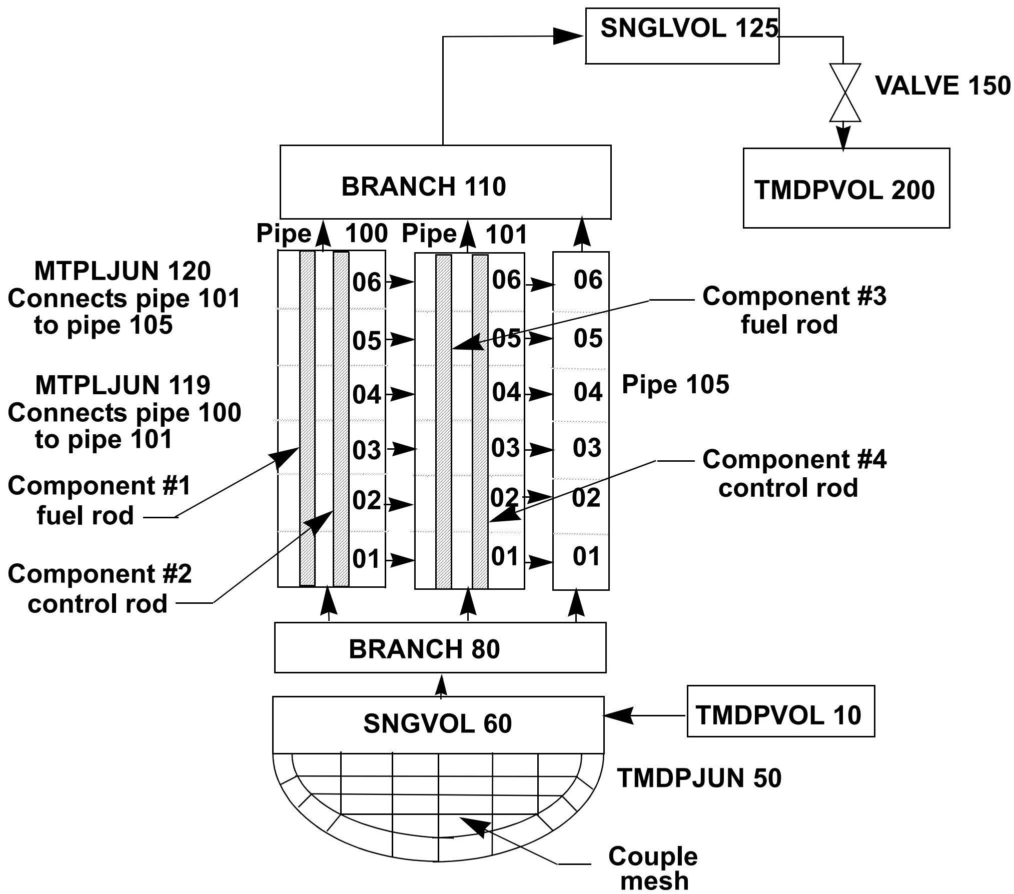


**Figure 6-3.** Nodalization diagram for Simple Cheap Vessel Problem.

The Simple Cheap Vessel Problem is the most rigorous of the benchmark problems, in that the core is modeled with two groups of fuel rod and two groups of Ag/In/Cd control rod components, and a COUPLE mesh has been added, as shown in Figure 6-3. Each group of fuel rods represents 18,408 rods and each group of control rods represents 118 rods. These groups of fuel and control rods are representative of an entire reactor core. This problem is intended to test the meltdown of the core, and the transfer of core molten material to the lower head.

The core volumes are initialized with steam, and allowed to heat up, meltdown, and relocate to the lower head. This problem is considered successful if it runs to completion without error, and without generating non-physical results.

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# APPENDIX A - SCDAP/RELAP5-3D© INPUT REQUIREMENTS

# CONTENTS

# FIGURES

# TABLES

# A1. INTRODUCTION

Complete descriptions of data deck organization and data card requirements for RELAP models of SCDAP/RELAP5-3D© are presented Reference A-1. This appendix provides data card requirements pertaining to models used in the SCDAP and COUPLE models of SCDAP/RELAP5-3D©.

# A2. CARDS 301 THROUGH 399, MINOR EDIT REQUESTS

Complete descriptions of minor edit data card requirements for RELAP models of SCDAP/RELAP5-3D© are presented Reference A-1. This section provides data card requirements pertaining to models used in the SCDAP and COUPLE models of SCDAP/RELAP5-3D©.

## A2.1 SCDAP Quantities

### A2.1.1 Plotting of Variables Calculated by SCDAP and HTGR Models

Table A2-1 describes plot variables that characterize the behavior of Light Water Reactor (LWR) reactor cores and Table A2-2 describes plot variables that characterize the behavior of High Temperature Gas Reactor (HTGR) cores. The variables in Table A2-2 are used to plot information for describing the general characteristics of heat transfer in HTGRs and for auditing the energy balance of the heat transfer calculations. The values of these plot variables are stored so as to be plotted as a function of time. The only other variable plotted for HTGR analysis is variable cadct, which is described in Table A2-5. The underlined variables are default variables that are written to the plot file for every analysis, while 208 cards are required to save non-underlined variables for plotting, as documented in Volume 2 of Reference A-1. It should be noted that if the default variables are requested on a 208 card, they will be written to the plot file twice.

**Table A2-1.** Variables that characterize the response of a LWR core and fuel bundles .

| Code | Index | Quantity |
|---|---|---|
| <u>BGNHG</u> | 0 | Core or test fuel bundle nuclear heat generation (W). |
| <u>BGMCT</u> | 0 | Core or test fuel bundle maximum surface temperature (K). |
| <u>BGTFPRN</u> | 0 | Core cumulative noncondensable fission product release (kg). |
| <u>BGTFPRS</u> | 0 | Core cumulative soluble fission product release (kg). |
| <u>BGTH</u> | 0 | Core total hydrogen generation rate (kg/s). |
| <u>BGTHQ</u> | 0 | Core total oxidation heat generation (W). |
| <u>BGTHQU</u> | 0 | Core oxidation heat generation due to uranium oxidation (W). |
| <u>BGTHU</u> | 0 | Core hydrogen generation rate due to uranium oxidation (kg/s). |
| <u>CRUCB</u> | 0 | Indicator of whether crust supporting molten pool has failed: 0.0 = no, 1.0 = yes. |

**Table A2-1.** Variables that characterize the response of a LWR core and fuel bundles (continued).

| Code | Index | Quantity |
|---|---|---|
| FPMASR | 1 - Xe<br>2 - Kr<br>3 - Cs<br>4 - I<br>5 - Te | Cumulative mass released (kg, lb). |
| FPFRCR | | Fractional mass released (unitless). |
| REPOOL | 0 | Equivalent radius of the molten pool of core material (m). |
| SHQIN | 0 | Total heat flowing through the inside surface of the flow shroud (W). Available only if the shroud component is input. |
| SHQOUT | 0 | Total heat flowing through the outside surface of the flow shroud (W). Available only if the shroud component is input. |
| TCORAV | 0 | Average temperature of reactor core (K). |

**Table A2-2.** Variables that characterize the response of an HTGR core. .

| Code | Index | Quantity |
|---|---|---|
| BGMCT | 0 | Maximum temperature in HGTR core (K). |
| BGNHG | 0 | Total fission and decay heat generation in HTGR (W). |
| BGTHQU | 0 | Rate of heat transfer to atmosphere and containment (W). |
| REPOOL | 0 | Integration with respect to time of fission and decay heat in reactor core (J). |
| BGTHU | 0 | Integration with respect to time of change in stored energy of all structures in HTGR system and heat transferred to atmosphere (J). |
| BGTH | 0 | Integration with respect to time of heat transferred to atmosphere due to natural circulation cooling (J). |
| BGTFPRN | 0 | Sum of rate of radiative and convective heat transfer to containment (W). |
| BGTFPRS | 0 | Rate of heat transfer to containment by convection (W). |
| SHQIN | 0 | Rate of heat transfer to containment by radiation (W). |
| SHQOUT | 0 | Rate of heat transfer to atmosphere (W). |
| BGTHQ | 0 | Rate of energy production due to oxidation of graphite in reactor core (W). |

### A2.1.2 SCDAP Component Quantities

Table A2-3 describes the variables that characterize the response of each component. The index, jj, is the component number of interest. The underlined variables are default variables which are written to the plot file for every analysis, while 208 cards are required to save non-underlined variables for plotting, as documented in Volume 2 of Reference A-1. It should be noted that if the default variables are requested on a 208 card, they will be written to the plot file twice.

**Table A2-3.** Variables that characterize the response of each component.

| Code | Index | Quantity |
|---|---|---|
| PGAS | jj | Gas pressure inside component jj (MPa). |
| ZBTCOH | jj | Elevation of the bottom surface of the cohesive debris bed for component jj (m). |
| ZBTRUB | jj | Elevation of the bottom of the rubble debris bed for component jj (m). |
| ZTPCOH | jj | Elevation of the top surface of the cohesive debris bed for component jj (m). |
| ZTPRUB | jj | Elevation of the top of the rubble debris bed for component jj (m). |

### A2.1.3 SCDAP Axial Dependent Quantities

Table A2-4 describes the variables that characterize the response of each axial node of each component. The index, kkjj, is the axial node, kk, and the component number, jj, of interest. The underlined variables are default variables which are written to the plot file for every analysis, while 208 cards are required to save non-underlined variables for plotting, as documented in Volume 2 of Reference A-1. It should be noted that if the default variables are requested on a 208 card, they will be written to the plot file twice.

**Table A2-4.** Variables that characterize the response of each axial node of each component.

| Code | Index | Quantity |
|---|---|---|
| BRCHV | kkjj | Indicator of whether double-sided oxidation is taking place at axial node kk of component jj: 0.0 = no, 1.0 = yes. |
| GGIVY | nnjj | Mass of nn-th species of fission product released from SCDAP component jj (kg). |
| DAMLEV | kkjj | Level of damage at axial node kk of component jj (unitless). See Table A2-7. |
| DZFRCQ | kkjj | Height of cohesive debris at axial node kk of component jj (m). |

**Table A2-4.** Variables that characterize the response of each axial node of each component. (continued)

| Code | Index | Quantity |
|---|---|---|
| EFFOXD | kkjj | Effective oxide thickness at axial node kk of component jj. SCDAP/RELAP5-3D© now uses two oxide thicknesses: the first is the physical oxide thickness, OXDEO, and the second is an effective thickness, used to calculate the oxidation rate. |
| H2OXD2 | kkjj | Hydrogen production rate at axial node kk of component jj (kg/s). |
| HFIXF | kkjj | Convective heat transfer coefficient for liquid phase at axial node k of component jj ($W/m^2 \cdot K$). |
| HFIXG | kkjj | Convective heat transfer coefficient for vapor phase at axcial node k of component jj ($W/m^2 \cdot K$). |
| HOOP | kkjj | Cladding hoop strain of component jj at axial node kk. |
| OXDEO | kkjj | Oxide thickness of the cladding at axial node kk of component jj (m). |
| QFLUX0 | kkjj | Total heat flux at axial node kk of component jj ($W/m^2$). |
| QSCD | kkjj | Heat transferred from SCDAP component jj at axial node kk to fluid at this location (W). |
| QWGSCD | kkjj | Heat transferred to vapor phase of fluid from SCDAP component jj at axial node kk (W). |
| RCI | kkjj | Inside radius of the cladding at axial node kk of component jj (m). |
| RCO | kkjj | Outside radius of the cladding (not including the crust of solidified material) at axial node kk of component jj (m). |
| RNALF | kkjj | Inner radius of the alpha oxide layer at axial node kk of component jj (m). |
| RNOXD | kkjj | Inner radius of the oxide layer at axial node kk of component jj (m). |
| ROCRST | kkjj | Outside radius of cladding (including the crust of the solidified material) of component jj at axial node kk (m). |
| RPEL | kkjj | Radius of fuel pellet of component jj at axial node kk (m). |
| RULIQ | kkjj | Outside radius of the solid part of the fuel pellet at axial node kk of component jj (m). |

**Table A2-4.** Variables that characterize the response of each axial node of each component. (continued)

| Code | Index | Quantity |
|---|---|---|
| SCDCHF | kkjj | Critical heat flux at surface of SCDAP component jj at axial node kk ($W/m^2$). |
| WFROSR | kkjj | Mass of stainless steel resolidified at axial node kk of component jj per individual rod (kg). |
| WFROUO | kkjj | Mass of $UO_2$ resolidified at axial node kk of component jj (kg). |
| WFROZR | kkjj | Mass of zircaloy resolidified at axial node kk of component jj (kg). |
| WREMSR | kkjj | Mass of stainless steel remaining at axial node kk of component jj (kg). |
| WREMUO | kkjj | Mass of removed fuel of component jj at axial node kk (kg). |
| WREMZR | kkjj | Mass of removed cladding of component jj at axial node kk (kg). |

### A2.1.4 SCDAP General

The subfields of the index are explained for each variable in Table A2-5. The underlined variables are default variables which are written to the plot file for every analysis, while 208 cards are required to save non-underlined variables for plotting, as documented in Volume 2 of Reference A-1. It should be noted that if the default variables are requested on a 208 card, they will be written to the plot file twice.

**Table A2-5.** Variables that characterize temperature and creep rupture.

| Code | Index | Quantity |
|---|---|---|
| <u>CADCT</u>[1] | iikkjj | Temperature of radial node number ii, axial node number kk, and component number jj (K). |
| DCREPC | ii | Fraction of life expended for ii-th COUPLE heat structure identified for creep rupture calculation. |
| DCREPH | ii | Fraction of life expended for ii-th RELAP5 heat structure identified for creep rupture calculation. |

1. The component surface and centerline temperatures are always written to the restart/plot file at each minor edit frequency. A 208 card is required to save the temperature at any other radial node for plotting.

**Table A2-6.** Fission product species.

| Index | Specie | Index | Specie |
|---|---|---|---|
| 1 | I | | |
| 2 | CsI | 10 | Sn |
| 3 | CsOH | 11 | Fe |
| 4 | Te | 12 | Ru |
| 5 | HI | 13 | Ba |
| 6 | HTe | 14 | Sb |
| 7 | CD | 15 | Zn |
| 8 | Ag | 16 | Xe |
| 9 | UO2 | 17 | Kr |

**Table A2-7.** Damage state.

| DAMLEV | Damage state |
|---|---|
| 0.0 | Intact geometry |
| 0.1 | Rupture due to ballooning |
| 0.2 | Rubble (fragmented) |
| 0.4 | Cohesive debris |
| 1.0 | Molten pool |

### A2.1.5 SCDAP Quantities for BWR Blade/Box Component

The expanded edit/plot variables defined for the BWR blade/box component are listed in Table A2-8. Although the variable names are identical to those used for other SCDAP components, the definitions listed below apply only to BWR blade/box components. The subfields of the index are ii for the radial node number, kk for the axial node number, and jj for the component number.

**Table A2-8.** Edit/plot variables defined for the BWR blade/box component.

| Code | Index | Quantity |
|---|---|---|
| CADCT | iikkjj | Temperatures (K) at radial node ii and axial node kk of component jj. For a BWR blade/box component, valid values of radial node ii are 1 - 14. |

**Table A2-8.** Edit/plot variables defined for the BWR blade/box component.

| Code | Index | Quantity |
|---|---|---|
| DAMLEV | kkjj | Level of damage (unitless) at axial node kk of component jj. For a BWR blade/box component, this indicates when the channel box wall has failed and a flow path has opened between the interstitial and fuel bundle coolant volumes.<br>0.0 = Both channel box segments intact.<br>0.1 = Channel box segment 1 gone.<br>0.2 = Channel box segment 2 gone.<br>0.3 = Both channel box segments gone. |
| H2OXD2 | kkjj | Total hydrogen production rate (kg/s) at axial node kk of component jj. For a BWR blade/box component, this is the total hydrogen from the control blade and both sides of the channel box. |
| OXDEO | kkjj | Frozen crust thickness (m) on the interstitial side of channel box segment 2 at axial node kk of component jj. |
| RCI | kkjj | Equivalent thickness (m) of the intact control blade sheath at axial node kk of component jj. |
| RCO | kkjj | Frozen crust thickness (m) on the control blade at axial node kk of component jj. |
| ROCRST | kkjj | Thickness (m) of the intact channel box segment 1 at axial node kk of component jj. |
| RPEL | kkjj | Thickness (m) of the intact channel box segment 2 at axial node kk of component jj. |
| RULIQ | kkjj | Equivalent thickness (m) of the intact absorber rodlet ($B_4C$ and stainless steel) at axial node kk of component jj. |
| WREMUO | kkjj | Frozen crust thickness (m) on the fuel bundle side of channel box segment 2 at axial node kk of component jj. |
| WREMZR | kkjj | Frozen crust thickness (m) on the fuel bundle side of channel box segment 1 at axial node kk of component jj. |

# A2.2 COUPLE Quantities

## A2.2.1 Element or Node Specific Parameters

Table A2-9 describes quantities which are specific to a single node or element, and may be requested or plotted. The underlined variables that are default written to the plot file for every analysis, while 208 cards are required to save non-underlined variables for plotting, as documented in Volume 2 of Reference

A-1. It should be noted that if the default variables are requested on a 208 card, they will be written to the plot file twice.

**Table A2-9.** COUPLE node quantities.

| Code | Index | Quantity |
|---|---|---|
| AFBULK | jjkk | Indicator of type of material in element jj of COUPLE mesh kk. See Table A2-11. |
| EVHTC | jj | Ex-vessel heat transfer coefficient at convection heat transfer node jj. |
| FPDEB | iijjkk | Fission product ii in element jj in COUPLE mesh number kk. |
| FRACML | jjkk | Fraction of COUPLE element jj in COUPLE mesh number kk that has melted. |
| GAPHTC | jjkk | Heat transfer coefficient for jj-th finite element (gap element) of mesh number kk (W/m2 $\cdot$ K). |
| MPHTC | jjkk | Heat transfer coefficient at liquid-solid interface for node jj of mesh number kk ($W/m^2 \cdot K$). |
| PORE | jjkk | Porosity of debris in element jj of COUPLE mesh kk |
| POWDB | jjkk | Power in element jj of COUPLE mesh kk ($W/m^3$). |
| TMLTEL | jjkk | Melting temperature of material in element kk of COUPLE mesh kk (K). |
| <u>TMPCOU</u> | jjkk | Debris bed temperature at node jj in COUPLE mesh number kk (K). |
| <u>TOTHTC</u> | jjkk | Convective heat transfer coefficient at node jj of COUPLE mesh kk ($W/m^2 \cdot K$). |

### A2.2.2 COUPLE Mesh Quantities

Table A2-10 defines COUPLE quantities which are characteristic of an entire mesh. The underlined variables are default variables which are written to the plot file for every analysis, while 208 cards are required to save non-underlined variables for plotting, as documented in Volume 2 of Reference A-1. It should be noted that if the default variables are requested on a 208 card, they will be written to the plot file twice.

**Table A2-10.** COUPLE mesh quantities.

| Code | Index | Quantity |
|---|---|---|
| <u>CSENRG</u> | kk | Total internal energy in structural material that supports debris (J). |
| <u>DEBQUP</u> | kk | Total rate of heat transfer by convection from top surface of debris (W). |

**Table A2-10.** COUPLE mesh quantities. (continued)

| Code | Index | Quantity |
|---|---|---|
| DENRGY | kk | Total internal energy of debris (J). |
| HGTDEB | kk | Debris bed height in COUPLE mesh kk (m). |
| INTPOW | kk | Integral with respect to time of total power in debris (J). |
| INTQ | kk | Integral with respect to time of total transfer from debris and structural material to fluid at boundaries of debris and structural material (J). |
| LIQAVG | kk | Average liquefied debris temperature (K). |
| LIQAG | kk | Mass of liquefied silver in mesh kk (kg). |
| LIQFE | kk | Mass of liquefied steel in mesh kk (kg). |
| LIQUO2 | kk | Mass of liquefied $UO_2$ in mesh kk (kg). |
| LIQZO2 | kk | Mass of liquefied $ZrO_2$ in mesh kk (kg). |
| LIQZR | kk | Mass of liquefied zirconium in mesh kk (kg). |
| MASLIQ | kk | Liquefied mass in mesh kk (kg). |
| MASSAG | kk | Total mass of silver in mesh kk (kg). |
| MASSAL | kk | Total mass of aluminum in mesh kk (kg). |
| MASB4C | kk | Total mass of $B_4C$ in mesh kk (kg). |
| MASSCD | kk | Total mass of cadmium in mesh kk (kg). |
| MASSFE | kk | Total mass of stainless steel in mesh kk (kg). |
| MASSLI | kk | Total mass of lithium in mesh kk (kg). |
| MASSU | kk | Total mass of metallic uranium in mesh kk (kg). |
| MASUO2 | kk | Total mass of uranium dioxide ($UO_2$) in mesh kk (kg). |
| MASSZR | kk | Total mass of zircaloy in mesh kk (kg). |
| MASZO2 | kk | Total mass of zirconium oxide in mesh kk (kg). |
| MPPDEN | kk | Molten pool power density ($W/m^3$) |
| PDBTOT | kk | Total power in material that has slumped to lower head (W). |
| TMPDAV | kk | Average debris temperature in COUPLE mesh number kk (K). |
| TMPDMX | kk | Maximum debris bed temperature in COUPLE mesh number kk (K). |
| TWALMX | kk | Maximum temperature of structural material in COUPLE mesh kk (K) |

**Table A2-11.** COUPLE material indicator.

| AFBULK | Type of material |
|---|---|
| 0.3 | Mostly Ag-In-Cd |
| 0.4 | Mostly stainless steel |
| 0.5 | Mostly Zr |
| 0.6 | Mostly $ZrO_2$ |
| 0.7 | More than 50% $UO_2$ |
| 1.0 | More than 70% $UO_2$ |

# A3. CREEP RUPTURE

The following cards are used to activate the creep rupture model. The temperature for this model may either come from a SCDAP/RELAP5-3D© heat structure, or from the COUPLE debris bed model. Card 21000000 and cards 21000001 through 21000009 are used to link the creep rupture model to the COUPLE debris bed, while cards 21000101 through 21000110 link the model to a SCDAP/RELAP5-3D© heat structure. Either or both types of cards may be entered.

These cards are optional for either a NEW or RESTART problem. If the creep rupture model is linked to a COUPLE debris bed, then the COUPLE debris bed model must be activated.

## A3.1 CARD 21000000, COUPLE Creep Rupture Control

This card is optional if the COUPLE model is used but cannot be present if the COUPLE model is not used. All three values may be changed on RESTART.

W1(I) IMAT. Material index for COUPLE wall:

1 = A-508 Class 2 carbon steel (default).

2 = 316 stainless steel.

3 = Inconel 600.

W2(I) Containment volume. If specified as non-zero this volume is used as the containment volume. Default is zero.

W3(R) External pressure (Pa, $lb_f/in^2$). If W2 is > 0, then this value is ignored and the external pressure is taken from the containment volume, otherwise this value is the constant external pressure. Default is atmospheric pressure.

## A3.2 Cards 21000001 through 21000009, COUPLE Wall

Creep rupture may be modeled at a maximum of nine COUPLE locations (defined by parameter nrlcmx). At each creep rupture location, a maximum of eleven COUPLE mesh points may be used to define the temperature for the creep rupture model. The temperature at each mesh points is used to produce an average temperature, which is then used as the single temperature of that creep rupture location.

One Card 2100000I is read for each COUPLE wall creep rupture calculation for location I, and the specification of all mesh points for that location must be contained on that card.

If entered on a restart run, any Card 2100000I will cause the mesh points identifying the average temperature of location i to be replaced for that I. The creep rupture damage term for location I will also be reset to 0.0 at the time of restart. Therefore the user should not re-enter any creep rupture locations which the user does not wish to replace. On a restart run, one may also add new locations by specifying previously unused values of I. To remove location i on restart without replacement, specify W1 on Card 2100000I as 0.

Each Card 2100000I lists N (1 to 11) elements of the COUPLE grid, which describe location I on the COUPLE wall.

W1(I) ELEMENT 1.

WN(I) ELEMENT N.

## A3.3 Cards 21000101 through 21000110, Heat Structures

Creep rupture may be modeled at up to ten SCDAP/RELAP5-3D© heat structures. A COUPLE mesh need not be entered to model creep at a heat structure.

These cards are optional for either NEW or RESTART calculations. One Card 210001II is read for each creep rupture calculation location II, where the location is at the given heat structure.

If entered on a restart run, any Card 210001II will cause the mesh points identifying the average temperature of location II to be replaced. The creep rupture damage term for location II will also be reset to 0.0 at the time of restart. Therefore the user should not re-enter any creep rupture locations which the user does not wish to replace. On a restart run, one may also add new locations by specifying previously unused values of II. To remove location II on restart without replacement, specify W1 on Card 210001II as 0.

W1(I) Heat structure number. The heat structure for which creep rupture failure calculation is to be done. The format is CCCG00X, where CCC is the heat structure number and G is its geometry.

W2(I) Material index.

1 = A-508 Class 1 carbon steel.

2 = 316 stainless steel.

3 = Inconel 600.

W3(R) Inner (left) pressure (Pa, $lb_f/in^2$). If non-zero, this constant pressure is used. If zero, pressure is from adjacent volume. Default is zero.

W4(R) Outer (left) pressure (Pa, $lb_f/in^2$). If non-zero, this constant pressure is used. If zero, pressure is from adjacent volume. Default is zero.

# A4. INPUT FOR MODELING REACTOR CORE

The presence of cards described in this section activates the SCDAP (Severe Core Damage Analysis) portion of the code. Each card number begins with the digit ‘4’.

Comparative checks will occur during input processing for variable type, number of words on a card, range of normal use, and physical/code limits. Further checks will also be performed for consistency of input. For example, one consistency check will examine radial node placement and verify that radial nodes have been placed at material interfaces.

Input violations of variable type, number of words, physical limit, and consistency of input will result in an input error, but will not abort input processing. Error messages will be printed in the output file flagged with the character string “********”. If the input is outside the range of normal use, a warning message will be printed in the output file and marked with the character string “$$$$$$$$.”

To assist the user during deck building and input processing, selected ranges of allowable input will be identified with the card input descriptions. The range for a given input variable will be identified in the following manner:

Normal type - issue warning if out of range

$\underline{\mathbf{0.0}\boldsymbol{m}} < x \leq 2.0\boldsymbol{m}$

Underline - input error if out of range

## A4.1 Reactor Core Nodalization and Selection of Modeling Options

The first set of cards describe general core geometry, and are also used to input core-wide parameters. They are unique since they begin with the four digits ‘4000’.

### A4.1.1 Card 40000100, Nodalization and Type of Reactor

This card is used to define general control parameters and to control the types of facility dependent phenomena to be modeled.

This card is required for NEW problems, and cannot be changed for RESTART problems.

W1(I) Number of axial nodes. The range[1] is $2 \leq x \leq 100$.

1. The upper limit for the number of axial nodes in a SCDAP component is set in the code at compile time by the parameter ndax.

If a HTGR is being modeled (Cards 40010000 and subsequent cards are input), the axial nodalization defined on Card 40000100 and 40000201 is applied to the reactor core, reactor vessel, reactor containment and surrounding material, if any. If the reactor design includes a downcomer and upcomer for the cooling of the reactor vessel by natural circulation of air from the atmosphere, the axial nodalization also applies to these structures.

W2(I) Heat conduction flag. Always input the integer 1.

W3(I) Reactor environment.

This flag identifies phenomena for modeling fuel component meltdown and fission product release.

1 = PWR.

2 = BWR.

4 = ATR.

5 = Electrically heated core.

7 = HTGR.

W4(I) Power history type.

This flag is used to specify the decay power reduction caused by the release of volatile fission products after fuel disruption. Six different built-in correction relations are provided, as follows:

1 = Generic PWR (33,800 MWD/tU).

2 = TMI (3,250 MWD/tU).

3 = PBF Severe Fuel Damage Test Series.

4 = PBF (other test series).

5 = Full decay power.

6 = No decay power.

### A4.1.2 Cards 40000201 through 40000299, Axial Node Heights

This card is required for a NEW problem and cannot currently be changed for RESTART problems. The card format is two words per set in sequential expansion format.

W1(R) Axial node height (m, ft). The range is $0.0 \text{ m} < x \leq 2.0 \text{ m}$.

W2(I) Axial node. Node number used for sequential expansion.

If a HTGR is being modeled (W3(I) = 7 on Card 40000100), the only other input required is that defined in Section A11.

### A4.1.3 Card 40000300, Fuel Rod Meltdown and Oxidation

This card and cards 40000310, 40000320, and 40000330 are optional for NEW or RESTART problems. These cards should be omitted for best-estimate calculations. They can be used when information is wanted on the sensitivity of calculated results to parameters in the modeling of oxidation and meltdown with a large degree of uncertainty.

W1(R) Threshold temperature for re-slumping of stationary drops of relocated fuel rod cladding and dissolved fuel (K). Default value: 2800 K. Coefficient name: tmpfal.

W2(R) Multiplier on ultimate strength of fuel rod cladding oxide layer (unitless). Default value: 2.5. Coefficient name: frcoxf.

W3(R) Necessary fraction of coolant space filled with slumped cladding for further filling to not affect re-slumping of the slumped cladding and further filling to not affect oxidation of slumped cladding. Default = 0.55 (unitless). Coefficient name: epsox2.

W4(I) Option to suppress oxidation of fuel rod cladding directly below a molten pool, and thereby reduce possibility of small time steps; 0 = suppress oxidation, 1 = do not suppress oxidation, default= 1.

W5(R) Necessary fraction of coolant space filled with slumped cladding for affect on re-slumping of slumped cladding. Default value: 0.3. Coefficient name: fcirmv.

W6(R) Threshold fraction for oxidation of slumped cladding that prevents re-slumping of this material when its metallic part melts again (unitless). Default value: $4.5 \times 10^{-2}$. Coefficient name: tmplos.

W7(R) Minimum weight gain in oxygen of drops of slumped cladding before another spalling of the oxide layer on the drops occurs during reflood conditions (kg $O/m^2$). Default value: $1.7 \times 10^{-2}$. Coefficient name: cofhbs.

W8(R) Reduction factor on necessary fraction of oxidation of slumped cladding to prevent re-slumping upon melting (unitless). Default value: 0.4. Coefficient name: exphbs. W8 is applied in full to W6 when fraction of coolant space filled with slumped material is greater than W3. W8 is applied in part when fraction coolant space filled with slumped cladding is greater than W5.

W9(R) Multiplier applied to thickness of cladding oxide layer dissolved by dissolution into adjacent metallic layer. This thickness of dissolution is applied in equation for stress in oxide layer. Default value: 3.5 (unitless). Coefficient name: fdsinc.

### A4.1.4 Card 40000310, Fuel Rod Meltdown and Oxidation (Continuation)

W1(R) Minimum effective fraction of surface area of intact cladding exposed to steam at location with slumped material (unitless). Default value: 0.333. Coefficient name: tdrslp.

W2(R) Minimum thickness of oxide layer on cladding for cracking of oxide layer during reflood and quenching (m). Default value: 0.5 x $10^{-4}$. Coefficient name: tstrez.

W3(R) Effective diffusion coefficient for oxide layer of fuel rod cladding that cracks during reflood ($m^2/s$). Default value: $2.x10^{-6}$. Coefficent name: vdrop.

W4(R) Necessary value for sum of fraction of oxidation and fraction of coolant space filled with slumped material that results in durable oxide layer on fuel rod cladding at that location (unitless). Default value: 0.45. Coefficient name: blksup.

W5(R) Multipler on fraction of coolant space filled with slumped material in inequality measuring durability of oxide layer on fuel rod cladding and used with W4(R) of this card (unitless). Default value: 0.55. Coefficent name: drpsup.

W6(I) Input the integer “2”. This input parameter is not used.

W7(R) Maximum rate of heatup by oxidation of intact cladding of fuel rods (W/m). Default value = 15500. Coefficent name: fdpdis.

W8(R) Fraction of change in phase of fuel at location that results in location changing into configuration of molten pool, 0 = no melting of fuel, 1 = complete melting of fuel (unitless). Default value = 0.5. Variable name = rgptol.

W9(R) Threshold hoop strain for double-sided oxidation of fuel rod cladding (unitless). Default value: 0.12. Coefficient name: foxmtc.

### A4.1.5 Card 40000320, Molten Pool Spreading and Slumping

This card is optional for a NEW or RESTART problems. This card has been added to allow the user the ability to perform parametric studies on significant parameters, and is not required for a best-estimate calculation.

W1(R) Multiplication factor on fuel pellet diameter that defines minimum thickness that crust at bottom of molten pool must have in order to support and seal the molten pool (unitless). Default value: 1.0.

W2 (R) Minimum fractional flow area for outer-most flow channel in reactor core after fuel rods in this channel have become molten. This parameter is intended to provide a means of comparing analyses of severe accident results which may exhibit non-symmetrical molten pools. Refer to Figure A4-1. Default value: 0.5.

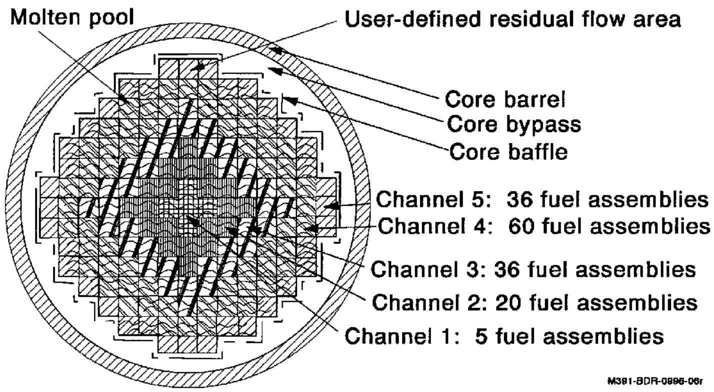


**Figure A4-1.** Definition of user-defined residual flow area after fuel melting for outermost flow channel in reactor core.

### A4.1.6 Card 40000330, Fuel Rod Fragmentation and Porous Debris Flow Losses

This card is optional for NEW or RESTART problems. This card is omitted except for sensitivity studies on the formation and thermal hydraulic behavior of porous debris.

W1(I) Index for selecting flow loss model for porous debris; 3 = detailed flow loss and heat transfer model for porous debris with transition smoothing models for porous debris not applied, 4 = detailed flow loss and heat transfer model for porous debris with transition smoothing models for porous debris applied, 2 = simplified flow loss and heat transfer model for porous debris (porous debris represented as intact rods with reduced hydraulic diameter). Default value: 3. Parameter name: nsmgeo.

W2(R) Increment of temperature above saturation temperature at which embrittled fuel rods fragment during quench (K). Default value: 100 K. Parameter name: tfrag.

W3(R) Maximum volume fraction of vapor for application of heat transfer regime for the single phase of liquid. Default value = 0.02. Parameter name: vlqthr.

W4(R) Maximum value of interphase drag for Tung and Dhir flow loss model[A-2] for porous debris for mist flow regime ($N/m^3$). Default value: $1.x10^9$. Parameter name: fifmsm.

W5(R) Maximum form loss coefficient for mist flow for Tung and Dhir flow loss model[A-2] for porous debris (unitless). Default value: 250. Parameter name: fmfmax.

W6(R) Maximum value of interphase drag for Tung and Dhir flow loss model for porous debris for flow regimes other than mist flow and inverted slip flow($N/m^3$). Default value: $1.x10^9$. Parameter name: fmfmax.

W7(R) Maximum value of interphase drag for Tung and Dhir flow loss model for porous debris for inverted slip flow regime ($N/m^3$). Default value: $1.x10^9$. Parameter name: fifsgm.

### A4.1.7 Card 40000400, Gamma Heating

This card is optional for a NEW problem, and cannot currently be changed for RESTART problems.

W1(R) Gamma heat fraction. The fraction of power used to directly heat the coolant by gamma heating. The default is 0.026, and the range[1] is $0.0 \leq x \leq 0.057$.

### A4.1.8 Card 40000500, Cladding Deformation and Oxidation

This card is optional for either NEW or RESTART problems and is used to define cladding ballooning parameters and two different models for oxidation. This card is omitted except for analyses to produce information for sensitivity studies or for fuel rods connected to unusually large upper plenums.

W1(R) Rupture hoop strain. The strain at which the cladding will rupture. The default is 0.18 and the range is $0.0 < x \leq W3$.

W2(R) Always input W1 + 0.02.

W3(R) Limit hoop strain. Strain limit for rod-to-rod contact. The default is 0.33 and the range[2]

is $0.0 < W3 \leq \frac{p - 2r}{p}$ where p is pitch of the fuel rods and r is the fuel rod radius.

W4(I) Pressure drop flag. Flag for modeling pressure drop due to ballooning. The default is 0.

0 = Pressure drop caused by ballooning is modeled.

1 = Pressure drop caused by ballooning is not modeled. This input is defined when a fuel rod has such a large upper plenum that a significant pressure drop does not occur as the cladding balloons. Some test rods in FzK severe fuel damage tests had such a characteristic.

W5(I) Index for selecting model for mass transfer of $H_2O$ from bulk fluid to cladding surface; 1 = RELAP5 model[A-1] (presence of noncondensible gases such as Argon taken into account), 2= Olander model[A-3] for binary diffusivity in mixtures of $H_2O$ and $H_2$. Default value: 1. Parameter name: noxmod.

W6(I) Index for selecting correlation for diffusivity of $ZrO_2$; 0= Olander correlation,[A-3] 1=Berdyshev correlation.[A-4] Default value: 0. Parameter name: mdzrdf.

1. Upper limit base on fission of $^{235}U$.
2. Based on rod-to-rod contact.

### A4.1.9 Card 40000600, Source of Component Power Data

This card is required for NEW problems, and may be changed for RESTART problems. The purpose of this card is to specify how the time-dependent core power is specified to SCDAP/RELAP5-3D©. A subsequent component-specific card (40CC1100) specifies the fraction of core power to be deposited in each component. Power in either molten pool or porous debris will be modified according to core power.

W1(A) Source of data (‘table’, ‘cntrlvar’ or ‘kinetics’).

W2(I) Table or control variable number (if necessary).

If the ‘kinetics’ option is specified, then the component power is calculated by the RELAP5 kinetics model. If the time-dependent core power is specified with either reactor kinetics or general table the units will be handled internally. If specified by a control variable, the power should be calculated in watts.

### A4.1.10 Card 40001000, Grid Spacer Elevation

This card is optional and is used to define the elevation of each grid spacer. If this card is not used, then no grid spacers will be modeled. It may not be changed on RESTART.

W1(R) Elevation (m, ft). Elevation of the first grid spacer. The bottom of the core is at elevation zero.

WN(R) Elevation (m, ft). Elevation of the grid spacer n. The bottom of the core is at elevation zero. The range is $0.0 \text{ m} < x \leq 10.0 \text{ m}$.

### A4.1.11 Cards 40001001 through 40001099, Grid Spacer Description

This card is required for a NEW problem only if a grid spacer elevation has been specified. This card cannot be changed for RESTART problems. Sequential expansion format is used.

W1 (I) Grid spacer material. Input one word per spacer.

0 = Zircaloy.

1 = Inconel.

W2(R) Mass of grid spacer (kg, $lb_m$). Mass per rod. Total mass of spacer divided by number of rods in array. The range is $0.0 \text{ kg} < x \leq 0.004 \text{ kg}$.

W3(R) Height of grid spacer (m, ft). The range is $0.0 \text{ m} < x < 0.125 \text{ m}$.

W4(R) Plate thickness of grid spacer (m, ft). The range is $0.0 \text{ m} < x \leq 0.01 \text{ m}$.

W5(R) Radius of contact (m, ft). The radius of a circle which will have the same area as the (R) contact area between the grid spacer and the fuel rod cladding. The range is $0.0 \text{ m} < x \leq 0.002 \text{ m}$.

W6(R) Loss coefficient for MOD3.3.

W7(I) Grid spacer number. Sequential expansion applies.

### A4.1.12 Cards 40001101 through 40001199, Core Bypass Volume Identification

These cards are used to specify the core bypass hydrodynamic volume, which are used by model for radial spreading of core melt. These cards are required for a NEW problem and may not be changed during RESTART problems.

W1(I) Number of the RELAP5 hydrodynamic volume at bottom of core bypass region (9-digit number).

WN(I) Number of RELAP5 N-th hydrodynamic volume in core bypass region, where N = 2 = second volume from bottom, N = 3 = third volume from bottom, and so forth.

### A4.1.13 Cards 40001201 through 40001299, Core Bypass Volume Elevations

These cards are used to specify the elevations of the core bypass volumes identified on Cards 40001101 through 40001199. The elevations are referenced from the bottom of the core to the top of each RELAP5 control volume.

W1(R) Elevation of bypass volume 1 (m, ft). Distance from bottom of core to top of bypass Volume 1, where Volume 1 is bottom most volume in core bypass region.

WN(R) Elevation of bypass Volume N (m, ft). Distance from bottom of core to top of bypass Volume N.

### A4.1.14 Card 40001500, User Definition of Porous Debris Region

This card is not input for analyses of nuclear power plants or analyses of tests on fuel rods. It is only input when an analysis is to be performed of a porous debris region that exists at the start of the analysis instead of evolving from fuel rods due to damage progression. This card is optional for NEW or RESTART problems.

W1(I) Index for selecting the flow loss model for porous debris; 1 = Catton and Chung model,[A-6] 2 = Tung and Dhir model.[A-2] Default value: 1. Parameter name: ndbth1.

W2(I) Number of rings in inner part of debris region. If the debris porosity and particle size are uniform from centerline to outside surface of the debris region, then a distinction between inner and outer parts of the debris region is not made. Maximum number of rings is 16. Each ring may have a distinctive temperature and stack of RELAP5 control volumes. Default value = 1. Parameter name = ndbjin.

W3(I) Index identifying material in inner ring of debris; 1 = stainless steel, 2 = $UO_2$, 3 = $ZrO_2$, 4

= Zr. Default value: 1. Parameter name: ndbmt1.

W4(R) Porosity of debris in inner ring. Default value = 0.5. Parameter name = pordb1.

W5(R) Diameter of particles in inner ring of debris (m). Default value: $1.x10^{-3}$m. Parameter name: diadb1

W6(R) Power density in inner ring of debris ($W/m^3$). Default value: 0.0. Parameter name: pwrdb1.

W7(I) Number of rings in outer part of debris region. If the debris porosity and particle size are uniform from centerline to outside surface of the debris region, then omit this word and the rest of the words on this card. Maximum number of rings in inner and outer debris regions must sum to 16 or less. Default value = 0. Parameter name = ndbjot.

W8(I) Index identifying material in outer ring of debris; 1 = stainless steel, 2 = $UO_2$, 3 = $ZrO_2$, 4 = Zr. Default value: 1. Parameter name: ndbmt2.

W9(R) Porosity of debris in outer ring. Default value = 0.5. Parameter name = pordb2.

W10(R) Diameter of particles in outer ring of debris (m). Default value: $1.x10^{-3}$m. Parameter name: diadb2

W11(R) Power density in outer ring of debris ($W/m^3$). Default value: 0.0. Parameter name: pwrdb2.

### A4.1.15 Card 40002000, Core Slumping Control Card

For a NEW SCDAP/RELAP5-3D© problem, this card is required with at least the first two words present. A default value is provided for the remaining input.

For a RESTART run, this card is optional. For Words 2 through 8, if input values are absent or are < 10.E-10, respective constants will be obtained from the restart file.

W1(I) Number of the RELAP5 control volume to receive any core region material that slumps to lower head.

W2(I) RELAP5 volume at top center of core. The bottom of this volume should be contiguous with the top of the core. This word may not be changed on RESTART.

W3(R) Minimum flow area per fuel rod in cohesive debris in core region ($m^2$). The default is 1.4E-6 $m^2$.

This parameter is used as follows: Let $A_o = (Pitch^2 - \frac{\pi d_r^2}{4})$; $d_r$ = diameter of rods, then if

$W3/A_o > 0.1$, cohesive debris formation does not result in complete flow blockage; otherwise it does. If one stack of RELAP5 control volumes overlays every first rod being analyzed, $W3(R) \geq 0.5\ A_o$.

## A4.2 User Defined Options

A limited number of options have been implemented within the SCDAP/RELAP5-3D©code to activate or deactivate specific models for code assessment. These options are activated (or deactivated) by entering a card with a sequence number equal to or greater than 40004001 and less than or equal to 40004999. The first word should be a recognized keyword from Table A4-1 and the second word should be a value as described by the second column.

These cards are optional on either NEW or RESTART problems.

**Table A4-1.** User defined options.

| Keyword | Value | Default | Meaning |
|---|---|---|---|
| h2xport | on/off | on | When ‘off’, all oxidation calculations are performed but hydrogen is not released to the coolant stream |
| deform | on/off | on | When ‘off’, cladding deformation calculations are disabled. |
| truncate | on/off | off | When ‘on’, heat flux to coolant limited. |
| convect | on/off | on | When ‘off’, convection heat transfer is disabled. |
| rad | on/off | on | When ‘off’, radiation heat transfer is disabled. |

## A4.3 User-Specified Materials

The user may specify material properties for material indices 9-12 and 50-95 which are defined on Card 4CCC0300 for a “shroud” type of component. A series of Cards 40009NN1, 40009NN2, and 40009NN3 must be entered for each material to be specified, where nn is the material number whose properties are being specified.

Material Indices are listed in Table A4-2. Materials 50 through 59 are entered as pairs, even index being the material and odd index being the oxide.

**Table A4-2.** User-specified materials.

| Index | Material |
|---|---|
| 1 | Zircaloy |
| 2 | Zr-U-O mixture (liquid) |

**Table A4-2.** User-specified materials. (Continued)

| Index | Material |
|---|---|
| 3 | Zr-U-O mixture (frozen) |
| 4 | Tungsten |
| 5 | $ZrO_2$ |
| 6 | Unirradiated fuel, $UO_2$ |
| 7 | Cracked fuel, $UO_2$ |
| 8 | Relocated fuel, $UO_2$ |
| 9 | Steam-gas atmosphere. User may specify properties |
| 10 | User-specified properties |
| 11 | User-specified properties |
| 12 | User-specified properties |
| 13 | Metallic uranium |
| 14 | Disabled |
| 15 | Aluminum |
| 16 | $Al_2O_3$ |
| 17 | Lithium |
| 18 | Stainless steel 304 |
| 19 | Stainless steel oxide |
| 20 | Control rod absorber material (Ag/In/Cd or $B_4C$) |
| 21 | Molybdenum (heater rod wire) |
| 22 | Copper (heater rod wire) |
| 50-59 | User-specified material properties |

Material properties as a function of temperature are defined by a table of values, with the material temperature as the independent variable and the material property as the dependent variable.

### A4.3.1 Card 40009NN0, Temperature

This card is optional for NEW and RESTART problems. This card is used to specify the temperatures at which the user-definable material properties are specified.

W1(R) Temperature #1 (K, $\circ$ F).

WN(R) Temperature #2 (K, $\circ$ F). A maximum of 10 data points may be entered.

If this card is not input the default values are as follows: 300, 550, 700, 873, 1,083, 1,173, 1,248, 1,700, 2,100, 2,500 (temperatures in degrees Kelvin).

### A4.3.2 Card 40009NN1, Specific Heat

This card is optional for NEW problems and cannot be input for RESTART problems. Note that the user may specify properties only for Materials 9, 10, 11, and 12. NN in the card number is the material index.

W1.. (R) Material specific heat at the ten values of temperatures shown above (J/kg•K), $\mathrm{Btu/lb \cdot {}^{\circ}F}$.

### A4.3.3 Card 40009NN2, Density

This card is optional for NEW problems and cannot be input for RESTART problems. Note that the user may specify properties only for Materials 9, 10, 11, and 12. NN is the material index.

W1.. (R) Material densities at the ten values of temperatures shown above (kg/m$^3$), lb/ft$^3$.

### A4.3.4 Card 40009NN3, Thermal Conductivity

This card is optional for NEW problems and cannot be input for RESTART problems. Note that the user may specify properties only for Materials 9, 10, 11, and 12. NN is the material index.

W1.. (R) Material thermal conductivity at the ten values of temperatures shown above (W/m•K), $\mathrm{Btu/ft \cdot {}^{\circ}F}$.

### A4.3.5 Card 40009NN4, Surface Emissivity

This card is optional for NEW problems and cannot be input for RESTART problems. Note that the user may specify properties only for Materials 9, 10, 11, and 12. NN is the material index.

W1.. (R) Material surface emissivity at the ten values of temperatures shown above (1/1).

### A4.3.6 Card 40009NN5, Thermal Expansion

This card is optional for NEW problems and cannot be input for RESTART problems. Note that the user may specify properties only for Materials 9, 10, 11, and 12. NN is the material index.

W1.. (R) Material thermal expansion at the ten values of temperatures shown above (1/1).

# A5. CORE COMPONENTS

The reactor core is described by a group of components. Each component may represent one or more fuel rods, control rods or other core elements.

## A5.1 Fuel Rod Component

This component describes a group of $UO_2$ fuel rods. The identification number of this component is "cc".All of the fuel rods that are described by this component are assumed to behave identically. Multiple groups of fuel rods may be described. It is recommended that for inner most group of fuel rods, cc = 01, and outer most group of fuel rods have the largest cc value for fuel rods.

### A5.1.1 Card 40CC0000, Fuel Rod Component

This card is required for fuel rod components and may not be input for RESTART calculations.

W1(A) Component name. An eight-character name that should be descriptive of this component.

W2(A) Component keyword. Enter the four-character word "*fuel.*"

### A5.1.2 Card 40CC0100, Number of Fuel Rods, Burnup, and Cladding and Internal Gas Composition

This card is required for fuel rod components, and may not be input for RESTART calculations.

W1(I) Number of rods. Number of rods simulated by this component. All rods simulated by a single component are assumed to behave identically.

W2(R) Fuel rod pitch (m, ft.). The distance from fuel rod center to fuel rod center of adjacent fuel rods. The range[1] is 0.0126 M ≤ x ≤ 0.0187 m.

W3(R) Average burnup of fuel (MW-s/kg). This word is optional. The default is 0.0 and the range is (MW-s/kg). 0.0 ≤ x ≤ 4752000.0

W4(I) Index indicating composition of fuel rod cladding; 1 = Zircaloy, 2 = MA956 alloy.

W5(R) Mole fraction of helium in gas inside fuel rod.

W6(R) Mole fraction of xenon in gas inside fuel rod.

W7(R) Mole fraction of krypton in gas inside fuel rod.

### A5.1.3 Card 40cc0110, Composition of Fuel

W1(R) Weight fraction of ThO2 in fuel. If W1(R) and W2(R) are both equal to 0.0, then the fuel is composed only of UO2.

1. All fuel performance and rod geometry range values are based on NUREG/CR-3950, PNL-5210, Vol. 6.

W2(R) Weight fraction of $PuO_2$ in fuel.

### A5.1.4 Card 40CC0200, Fuel Rod Plenum Geometry

This card is required for fuel rod components and may not be input for RESTART calculations. The volume input is used in the calculation of internal gas pressure.

W1(R) Plenum length (m, ft.). The range is between 3% and 11% of the rod length.

W2(R) Plenum void volume ($m^3$, $ft^3$). Enter the plenum volume less the volume occupied by the spring. The range is $0.0 < x \leq 0.000049$ $m^3$.

W3(R) Lower plenum void volume ($m^3$, $ft^3$). Enter the gas volume of the lower fuel rod plenum.

### A5.1.5 Cards 40CC0301 through 40CC0399, Fuel Rod Dimensions

This card is required for fuel rod components, and may not be input for RESTART calculations. Radial dimensions of the fuel rod materials are specified for each axial node.

W1(R) As-fabricated fuel pellet radius (m, ft.). The range is $0.00385 \text{ m} \leq x \leq 0.00685$ m. If this component represents a water rod, then define a fuel pellet radius of $1 \times 10^{-4}$ m.

W2(R) As-fabricated inner cladding radius (m, ft.). The range is W1 < x < W3 and $0.003935 \text{ m} \leq x \leq 0.00634$ m.

W3(R) As-fabricated outer cladding radius (m, ft.). The range is $W2 < x < \frac{W2 \text{ Card4ccc0100}}{2}$ and $0.00457 \text{ m} \leq x \leq 0.00715$ m.

W4(I) Axial node.

### A5.1.6 Card 40CC0400, Upper and Lower Hydraulic Volumes

This card is required for fuel rod components and may not be input for RESTART calculations. Specified on this card are the RELAP5 control volumes which will act as heat sinks for bottom crust of a molten pool or for top crust of a molten pool.

W1(I) RELAP5 control volume located just above fuel rod.

W2(I) RELAP5 control volume located just below fuel rod.

### A5.1.7 Cards 40CC0401 through 40CC0499, Hydraulic Volumes

This card is required for fuel rod components and may not be input for RESTART calculations. It specifies the RELAP5 hydraulic volumes that provide the boundary conditions for the core component. A hydraulic volume must be specified for each axial node of the component, but the same hydraulic volume may be specified for a number of axial nodes. The style of this card, specifying a volume number and an increment, has been designed to match the style RELAP5 uses to specify left and right boundary conditions for the heat structures. The user is referred to Cards 1CCCG501, in the RELAP5 heat structure specification, for further information.

W1(I) RELAP5 control volume number. This word specifies the hydrodynamic control volume number (of the form CCCNN0000) associated with the surface of this component. One volume number must be specified for each axial node of the component, starting with the bottom node (Node 1).

W2(I) Increment. This word (of the form NN0000) and W1 of this card are treated differently from the standard sequential expansion. W1 applies to the first axial node within a set. The increment is applied to W1 to obtain the volume connected to the next axial node. The increment is repeated up to the axial node identified by W3. W1 of the next set applies to the next axial node, and increments are applied as for the first set. The increment may be zero or nonzero, positive or negative.

W3(I) Axial node.

### A5.1.8 Cards 40CC0501 through 40CC0599, Radial Mesh Spacing

This card is required for fuel rod components and may not be input for RESTART calculations. This card specifies the radial nodalization. To correctly interpret the nodalization, all numbers for a specific axial node must be specified with a single card number. Use continuation cards if necessary. The radial nodalization may be specified by either of two formats, but not both.

Format 1

Specify the number of intervals to be used across each material. The code will divide the radial distance across each material into the number of equally spaced mesh intervals specified. The number of radial nodes will be n+1, which is the total number of intervals plus one. The maximum number of radial nodes is twenty.

W1(I) Number of equally spaced intervals across fuel.

W2(I) Number of intervals across gap. One interval is recommended.

W3(I) Number of equally spaced intervals across cladding.

W4(I) Axial node number.

Format 2

Specify the radial position of each radial node for each axial node. In this format, the user must be careful to input the same number of radial nodes for each axial node, although the position of the radial nodes may be changed for each axial node. The maximum number of radial nodes is twenty.

W1(R) Radius to radial node 1 (m, ft). Enter pellet center radius of 0.0.

WN(R) Radius to radial node N (m, ft.). Enter radial node N. Radial nodes must be placed at least at the material interfaces (i.e., fuel pellet radius, and cladding inner radius). Radial nodes must be entered in ascending order and end with the last node placed on the cladding outer surface.

WN+1(I) Axial node.

### A5.1.9 Cards 40CC0601 through 40CC0699, Initial Temperatures

This card is required for fuel rod components, and may not be changed on RESTART calculations.

W1 (R) Temperature (K, $^oF$). Initial temperature at Radial Node 1. The range is 300 K $\leq x \leq$ 3,123 K.

WN (R) Temperature N (K, $^oF$). Enter an initial temperature for each radial node to radial node N, which is the last radial node. The range is 300 K $\leq x \leq$ 3,123 K.

WN+1(I) Axial node. Input temperature at each radial node.

### A5.1.10 Card 40CC0801 through 40CC0899, Material Specification

This card is optional for NEW, and may not be changed on RESTART calculations. The user may specify material indices for the components. At least three material indices should be input.

W1(I) Material index for material layer closest to center of rod.

W2(I) Material index for next material layer.

WN(I) Material index for nth material layer.

The defaults for a fuel rod component are $UO_2$(index=6), fuel-cladding gap (index=9), and Zircaloy (index=1). Refer to Table A4-2 for a list of material indices.

### A5.1.11 Card 40CC1100, Power Multiplier

This card is optional for NEW and RESTART problems, and specifies the fraction of total core power which is generated in this component.

The approach to specify power is as follows. First, a total core time-dependent power is specified (Section A4.1.9). Then a component power multiplier (this card) is used to determine the fraction of core power deposited in this component. The power in a single fuel rod can then be determined by dividing the component power by the number of fuel rods represented by this component. The linear heat generation rate at an individual axial node is determined by multiplying the rod power by an axial power profile factor (Section A5.1.12 & Section A5.1.13) and dividing by the axial node length. The power density at a specific radial node can then be determined by multiplying the local linear heat generation rate by the radial power factor (Section A5.1.14) and dividing by the cross-sectional area associated with that radial node.

W1(R) Fraction. This is the fraction of the core power in this component. The range for this power multiplier is $0.0 \leq x \leq 1.0$, and the default is 0.0.

### A5.1.12 Card 40CC13P0, Axial Power Profile Time

In the card number, “P” is axial power profile number (start with Number 1). This card is required for

NEW problems and cannot currently be input for RESTART problems.

W1(R) End time for which this axial power profile applies (s).

### A5.1.13 Cards 40CC13P1 through 40CC13P9, Axial Power Profile Data

Card numbering is specified similarly to the previous card, with “P” in the card number indicating the axial power profile number. This information is required for each profile and must be specified for each axial node of the component. This input specifies the fraction of rod power which is deposited at the axial node. The axial power fraction will be normalized over the length of the component.

W1...(R) Axial power factor at axial nodes. The range is $0.1 \leq x \leq 1.4$, and the default is 1.0.

### A5.1.14 Cards 40CC1401 through 40CC1499, Radial Power Profile

This card is required for NEW problems and cannot be input for RESTART problems. The radial power factor is used to determine the power density at each radial node, based upon the local heat generation rate.

W1(R) Radial power factor.

W2(I) Radial node at which W1(R) applies.

The last radial node that is input must align with the outer radius of the fuel pellet. The range is $x \leq 20$, and the default power factor is 1.0.

### A5.1.15 Card 40CC1500, Shutdown Time and Fuel Density

This card is required for NEW problems and cannot be input for RESTART problems.

W1(R) Time of reactor shutdown (s). This word is required. If fuel rod power is being calculated by the RELAP5 reactor kinetics model (W2 = kinetics on Card 40000600), then W1 = $1 \times 10^8$ s.

W2(R) Fraction of fuel theoretical density. This word is required. The range of the fraction of fuel theoretical density is $0.94 \leq x \leq 0.96$.

### A5.1.16 Cards 40CC1601 through 40CC1699, Previous Power History

This card is optional for NEW problems and may not be changed on RESTART problems. A prior power history is required to initialize the fission product inventory (PARAGRASS). It is assumed that either a prior power history or the initial fission product inventory (see next card) will be specified prior to enabling the PARAGRASS calculation.

The power is assumed to be a series of plateaus, with no interpolation. The last power density in this table is the transient power density until the problem time exceeds the shutdown time. Time in this table is referenced to the start of the operation of the reactor and not to the start of the time in the transient analysis.

W1(R) Power history (W/m$^3$). The range is $40.57\times10^6\frac{W}{m^3} \le x \le 279.3\times10^6\frac{W}{m^3}$.

W2(R) Time (s).

### A5.1.17 Card 40CC2000, Fission Products Tracked by PARAGRASS Model

This card is optional for fuel rod components and may not be input for RESTART calculations. This card is entered when initial inventory of fission products is not to be calculated by the code based on prior power history.

W1... (A) Species name. Enter the species (xe, kr, cs, i) to be tracked.

### A5.1.18 Cards 40CC2001 through 40CC2099, PARAGRASS Species Mass

This card is required only if Card 40CC2000 above is entered.

W1(R) Mass of species (kg, lb/m). Enter the initial mass of the first species specified on Card 40CC2000.

WN(R) Mass of species N (kg, lb/m). Enter the initial mass of the next species specified on Card 40CC2000 and repeat until all species masses specified on Card 40CC2000 have been entered.

### A5.1.19 Card 40CC2100, Fission Products to be Tracked by CORSOR Model

This card is optional and may not be changed on RESTART calculations.

W1... (A) Species name. Enter the species (te, zr, sr, fe, ru, zr*, ba) to be tracked.

### A5.1.20 Cards 40CC2101 through 40CC2199, Initial Fuel Fission Product Mass

This card is required only if Card 40CC2100 above is present.

W1(R) Mass of species (kg, lb/m). Enter the initial mass of the first species specified on Card 40CC2100.

WN(R) Mass of species N (kg, lb/m). Enter the initial mass of the next species specified on Card 40CC2100 and repeat until all species masses specified have been entered.

### A5.1.21 Card 40CC2200, Gap Fission Products

This card is optional and may not be changed on RESTART calculations. This card is normally omitted so that inventory of fission products in fuel-cladding gap is defined by the codes' fission gas release model.

W1... (A) Species name. Enter the species (xe, kr, cs, i, te) to be tracked.

### A5.1.22 Cards 40CC2201 through 40CC2299, Initial Gap Fission Product Mass

This card is required only if Card 40CC2200 is present.

W1(R) Mass of species (kg, lb/m). Enter the initial mass of the first species specified on Card 40CC2200.

WN(R) Mass of species N (kg, lb/m). Enter the initial mass of the next species specified on Card 40CC2200 and repeat until all species masses specified have been entered.

### A5.1.23 Card 40CC3000, Gas Internal Pressure

This card is required for NEW problems and cannot be input for RESTART problems.

W1(R) Helium gas as-fabricated inventory in an individual fuel rod in this component group (kg).

W2(R) Internal gas pressure in rod (Pa). (This value is used only to define a first guess of initial internal pressure for iteration procedure, so accurate values not required.)

### A5.1.24 Cards 40CC3201 through 40CC3299, Time-Temperature-Pressure

This card is optional for NEW problems. If omitted, no variation occurs in boundary conditions for calculating temperature distribution in fuel rod during burnup period before transient. This card cannot currently be input for RESTART problems. This card is normally omitted.

W1(R) Time (s). The time to which the axial surface temperature profile and fuel average hydrostatic pressure are used

W2(R) Cladding surface temperature (K).

W3(R) Fuel hydrostatic pressure (Pa).

### A5.1.25 Card 40CC4000, Option Definition

This card is optional for NEW problems and cannot currently be input for RESTART problems.

W1(A) Keyword to identify optional model to be applied.

W2(A) Flag specifying whether to apply model. (‘on’ or ‘off’).

The default for each model is ‘off’. See Table A5-1.

**Table A5-1.** Component optional models.

| Keyword | Value | Meaning if ‘ON’ |
|---|---|---|
| limit | on / off | oxidation is limited due to rate of steam diffusion through hydrogen. |

### A5.1.26 Cards 40CC5101 through 40CC5199, Gap Conductance

This card is optional and may not be changed on RESTART. The intended use is to allow the SCDAP calculated steady-state temperature profile to better match an independent steady-state temperature profile by specifying the steady-state gap conductance. In other words, Cards 40CC5101 and 40CC5201 can be used to set the internal energy in fuel rods at the start of a transient to the internal energy calculated by a detailed steady-state analysis fuel rod code such as FRAPCON-3.[A-5] If this card is not entered, the gap conductance will be calculated by the code. Sequential expansion applies.

W1(R) Gap conductance at steady-state conditions just before start of transient ($W/m^2 \bullet {}^2K$, $Btu/s^2 \bullet ft^{2\,2} \times {}^oF$)

W2(I) Axial node.

### A5.1.27 Cards 40CC5201 through 40CC5299, Fuel Thermal Conductivity

This card is optional and may not be changed on RESTART. Sequential expansion applies.

W1(R) Fuel thermal conductivity multiplier. The default is 1.0.

W2(I) Axial node.

## A5.2 Simulator Component

This input describes a group of electrically heated fuel rod simulators.

### A5.2.1 Card 40CC0000, Simulator Component

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(A) Component name.

W2(A) Component type -- *cora.*

### A5.2.2 Card 40CC0100, Number of Rods

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(I) Number of rods.

W2(R) Rod pitch (m). The range is $0.0126\ m \leq x \leq 0.0187\ m$.

### A5.2.3 Card 40CC0200, Simulator Rod Geometry

This card is required for NEW problems and cannot currently be input for RESTART problems. Two input variables are required. If appropriate, a third value may be specified.

W1(R) Plenum length (m, ft), the range is between 3% and 11% of the rod length.

W2(R) Plenum volume ($m^3$). The range is $0.0 < x \leq 0.000049\ m^3$.

W3(R) Lower plenum volume, if applicable ($m^3$, $ft^3$).

### A5.2.4 Card 40CC0250, Upper Plenum Boundary Conditions

This card describes the source of sink temperature data to be used to model axial heat conduction calculations from the top of the simulator rod.

This card is optional for NEW problems and cannot currently be input for RESTART problems.

W1(A) Keyword. The default is no axial heat conduction is modeled.

control = sink temperature defined by control variable.
table = sink temperature define by general table.

W2(I) Upper boundary control variable or RELAP5 table number.

### A5.2.5 Card 40CC0251, Lower Plenum Boundary Conditions

This card describes the source of sink temperature data to be used to model axial heat conduction calculations from the bottom of the simulator rod. This card is optional for NEW problems, and cannot currently be input for RESTART problems.

W1(A) Keyword. The default is no axial heat conduction is modeled.

control = sink temperature defined by control variable.
table = sink temperature define by general table.

W2(I) Lower boundary control variable or RELAP5 table number.

### A5.2.6 Card 40CC0300, Heating Element

This card is required for all simulator components, and may not be specified on RESTART.

W1(R) Radius of tungsten (m, ft). The remaining words are required for special option ‘cora’ not equal to zero.

W2(R) Resistance in flexible cabling (OHMS). The remaining words are required for special option ‘cora’ > 0.

W3(R) Radius of Molybdenum (ft, m).

W4(I) Number of electrode zones.

### A5.2.7 Cards 40CC0301 through 40CC0399, Simulator Dimensions

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(R) Fuel pellet radius (m). The range is $0.00385\ m \leq x \leq 0.00685$ m.

W2(R) Inner cladding radius (m). The range is W1 < x < W3 and 0.003935 m $\leq$ x $\leq$ 0.00634 m.

W3(R) Outer cladding radius (m). The range is $W2 < x < \frac{W2\ \text{Card}\ 4\text{CCC}0100}{2}$ and 0.00457 m $\leq$ x $\leq$ 0.00715 m.

W4(I) Axial node number.

### A5.2.8 Card 40CC0400, Upper and Lower Hydraulic Volumes

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(I) RELAP5 volume located above simulator rod.

W2(I) RELAP5 volume located below simulator rod.

### A5.2.9 Cards 40CC0401 through 40CC0499, Hydraulic Volumes

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(I) RELAP5 volume number. One volume number for each axial node, starting with Node 1.

### A5.2.10 Cards 40CC0501 through 40CC0599, Radial Mesh Spacing

This card is required for NEW problems and cannot currently be input for RESTART problems. The information may be entered in either Format 1 or 2, but not both.

Format 1

Specify the number of intervals to be used across each material. The code will divide the radial distance across each material into the number of equally spaced mesh intervals specified. The number of radial nodes will be n+1, which is the total number of intervals plus one.

W1(I) Number of equally spaced intervals across the fuel.

W2(I) Number of intervals across gap. One interval is recommended.

W3(I) Number of equally spaced nodes across the cladding.

W4(I) Axial node number.

Format 2

Specify the radial position of each radial node for each axial node. In this format, the user must be careful to input the same number of radial nodes for each axial node, although the position of the radial nodes may be changed for each axial node.

W1(R) Radius to radial node 1 (m, ft). Enter pellet center radius of 0.0.

WN(R) Radius to radial node N (m, ft.). Enter radial node N. Radial nodes must be placed at least at the material interfaces (i.e., fuel pellet radius, and cladding inner radius). Radial nodes must be entered in ascending order and end with the last node placed on the cladding outer surface.

WN+1(I) Axial node.

### A5.2.11 Cards 40CC0601 through 40CC0699, Initial Temperatures

These cards use both axial and radial self-expansion. They are required for NEW problems and cannot currently be input for RESTART problems.

W1... (R) Initial temperature at radial node 1 (K). The range is 300 K $\leq$ x $\leq$ 3,123 K.

### A5.2.12 Card 40CC1100, Power Multiplier

This card is optional for NEW and RESTART problems, and specifies the fraction of total core power which is generated in this component.

The approach to specify power is as follows. First, a total core time-dependent power is specified (Section A4.1.9). Then a component power multiplier (this card) is used to determine the fraction of core power deposited in this fraction. The power in a single simulator can then be determined by dividing the component power by the number of simulators represented by this component. The linear heat generation rate at an individual axial node is determined by multiplying the rod power by an axial power profile factor (Section A5.2.13 & Section A5.2.14) and dividing by the axial node length. The power density at a specific radial node can then be determined by multiplying the local linear heat generation rate by the radial power factor (Section A5.2.15) and dividing by the cross-sectional area associated with that radial node.

W1(R) Fraction. This is the fraction of the core power in this component.

The range for this power multiplier is 0.0 $\leq$ x $\leq$ 1.0, and the default is 0.0.

### A5.2.13 Card 40CC13P0, Axial Power Profile Time

In the card number, “P” is axial power profile number (start with Number 1).

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(R) End time for which this axial power profile applies (s).

### A5.2.14 Cards 40CC13P1 through 40CC13P9, Axial Power Profile Data

Card numbering is specified similarly to the previous card, with “P” in the card number indicating the axial power profile number. This information is required for each profile and must be specified for each axial node of the component. This input specifies the fraction of rod power which is deposited at the axial node. The axial power fraction will be normalized over the length of the component.

W1... (R) Axial power factor at axial nodes.

The range is $0.1 \leq x \leq 1.4$, and the default is 1.0.

### A5.2.15 Cards 40CC1401 through 40CC1499, Radial Power Profile

This card is required for NEW problems and cannot currently be input for RESTART problems. The radial power factor is used to determine the power density at each radial node, based upon the local heat generation rate.

W1(R) Radial power factor.

W2(I) Radial node at which W1(R) applies.

The last radial node that is input must align with the outer radius of the fuel pellet. The range is $x \leq 20$, and the default power factor is 1.0.

### A5.2.16 Card 40CC1500, Shutdown Time and Fuel Density

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(R) Time of reactor shutdown (s). This word is required. In general, W1 = 1. x $10^8$; this large value for W1 assures correct value for decay heat from RELAP5 reactor kinetics model.

W2(R) Fraction of fuel theoretical density. This word is required.

The range of the faction of fuel theoretical density is $0.94 \leq x \leq 0.96$.

### A5.2.17 Card 40CC9000, Volume of External Volumes

This card is optional for NEW problems and cannot currently be input for RESTART problems. This card specifies the volume of external volumes which may be attached to the void volume of electrical heater rods.

W1... (R) Volume of external volumes ($m^3$, $ft^3$).

Up to 10 external volumes may be specified.

### A5.2.18 Cards 40CC9001 through 40CC9099, External Volume Temperature History

This card is optional for NEW problems and cannot currently be input for RESTART problems. This card is used to specify the temperature history of external volumes which were specified in Section A5.2.17. The format of the card is to specify one point in the time-dependent temperature history of each volume.

W1(R) Time (s).

W2... (R) Temperature of external volume.

Word 2 is repeated for each external volume specified by card 40CC9000. A maximum of 10 time points may be specified.

# A5.3 PWR Control Rod Component

### A5.3.1 Card 40CC0000, PWR Component Identification

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(A) Component name.

W2(A) Component type -- control.

### A5.3.2 Card 40CC0100, Number of Rods

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(I) Number of rods. The range is $1 \leq x$.

W2(R) Control rod pitch (m). If a fuel rod component is entered, the control rod pitch should be equal to the pitch of the fuel rod, if it is in the same bundle.

### A5.3.3 Card 40CC0300, Materials

This card is optional for NEW problems and cannot currently be input for RESTART problems. This card is intended to specify materials for non-standard control rod configurations. The default materials are control rod absorber material (Ag-In-Cd for PWR's, $B_4C$ for BWR's), stainless steel, and zircaloy. If this card is present, three materials are specified by using the material indices specified in Table A4-2.

W1(I) Absorber material index. Material index for control rod absorber.

W2(I) Sheath material index. Material index for control rod sheath.

A gap is assumed between the second and third materials.

W3(I) Guide tube material index. Material index for guide tube.

### A5.3.4 Card 40CC0301 through 40CC0399, Geometry

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(R) Outer radius of control rod absorber (m, ft). The range is $0.0 < x < W2$.

W2(R) Outer radius of stainless steel sheath (m). The range is $W1 < x \leq W3$.

W3(R) Inner radius of zircaloy guide tube (m). The range is $W2 \leq x < W4$.

W4(R) Outer radius of zircaloy guide tube (m).

W5(I) Axial node for sequential expansion.

### A5.3.5 Card 40CC0400, Upper and Lower Hydraulic Volumes

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(I) RELAP5 control volume located above control rod.

W2(I) RELAP5 control volume located below control rod.

### A5.3.6 Cards 40CC0401 through 40CC0499, Hydraulic Volumes

This card specifies the RELAP5 hydrodynamic control volume which provides the boundary conditions for the control rod. A hydrodynamic volume must be specified for each axial node of the component. The style of this card, i.e., specifying a hydrodynamic volume number and an increment, has been chosen to match the style used by RELAP5 to specify heat structure left and right boundary conditions. This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(I) RELAP5 volume number.

W2(I) Increment.

W3(I) Axial node. Sequential expansion applies.

### A5.3.7 Cards 40CC0501 through 40CC0599, Radial Mesh Spacing

This card is required for NEW problems and cannot currently be input for RESTART problems.

This card may be entered in either Format 1 or 2, but you may not mix formats. A minimum of five radial nodes are required. Up to 20 radial nodes may be used. Nodes must be entered in consecutive order beginning with the first node at r = 0. Other required radial nodes must be placed at the outer radius of absorber material, the outer radius of stainless steel sheath, and the inner and outer radius of the zircaloy guide tube.

Format 1:

W1(I) Number of equally spaced intervals across the absorber material.

W2(I) Number of equally spaced intervals across the stainless steel sheath.

W3(I) Number of equally spaced nodes across the zircaloy guide tube.

W4(I) Axial node number for sequential expansion.

Format 2:

W1(R) Radial mesh spacing (m). Radial dimension of Node 1.

WN(R) Radial mesh spacing (m). Radial dimension of Node N.

WN+1(I) Axial node number.

Sequential expansion applies to this input.

### A5.3.8 Cards 40CC0601 through 40CC0699, Initial Temperatures

This card is required for control rod components and may not be changed on RESTART calculations.

W1(R) Temperature (K, $^oF$). Initial temperature at Radial Node 1. The range is 300 K $\leq x \leq$ 3,123 K.

WN(R) Temperature N (K, $^oF$). Enter an initial temperature for each radial node to radial node n, which is the last radial node. The range is 300 K $\leq x \leq$ 3,123 K.

WN+1(I) Axial node.

### A5.3.9 Card 40CC0700, Internal Gas Pressure

This card is optional for either NEW or RESTART calculations. It specifies the internal gas pressure of the control rod.

W1(R) Internal Gas Pressure (Pa, psi)

Default is 0.0 Pa.

### A5.3.10 Cards 40CC1100, Power Input

These cards are optional for either NEW or RESTART calculations. Refer to Section A5.1.11, Section A5.1.12, Section A5.1.13, and Section A5.1.14 for directions on entering control rod power. If no power input cards are used, then a power multiplier of 0.0 is applied to a uniform radial and axial power profile.

## A5.4 BWR Control Rods

### A5.4.1 Card 40CC0000, Component Identification

W1(A) Component name. Descriptive of role in system.

W2(A) Component type -- bwr.

### A5.4.2 Card 40CC0100, Number of Rods

W1(I) Number of rods in component.

### A5.4.3 Cards 40CC0301 through 40CC0399, Geometry

W1(R) Outer radii for $B_4C$ absorber. The range is 0.0 m < x < W2.

W2(R) Stainless steel cladding outer radii. The range is W1 < x < 0.00935 m.

W3(I) Axial number for sequential expansion.

### A5.4.4 Card 40CC0400, Upper and Lower Hydraulic Volumes

This card is required for NEW problems and may not be changed for RESTART problems.

W1(I) RELAP5 volume located above BWR rod.

W2(I) RELAP5 volume located below BWR rod.

### A5.4.5 Cards 40CC0401 through 40CC0499, Hydraulic Volumes

This card is required for NEW problems and may not be changed for RESTART problems.

W1(I) RELAP5 volume number. One word for each axial node.

### A5.4.6 Cards 40CC0601 through 40CC0699, Initial Temperatures

This card is required for NEW problems and may not be changed for RESTART problems.

W1(R) $B_4C$ absorber initial temperature. The range is 300 K $\leq$ x $\leq$ 1,723 K.

W2(R) Stainless steel cladding initial temperature. The range is 300 K $\leq$ x $\leq$ 1,723 K.

## A5.5 BWR Control Blade/Channel Box Component

These cards contain physical dimensions, hydraulic information, initial conditions, and radial spreading information for each BWR blade/channel box component.

### A5.5.1 Card 4CCC0000, Component Name and Type

This card is required for NEW problems and cannot currently be changed for RESTART problems.

W1(A) Component name. This is a descriptive name selected by the user. On most computers, there is an eight-character limit.

W2(A) Component type. Specify the keyword “bladebox.”

### A5.5.2 Card 4CCC0100, Number of Individual Structures

This card is required for NEW problems and cannot currently be changed for RESTART problems.

W1(I) Number of individual BWR blade/box structures in this component. An individual blade/box structure consists of half of a control blade divided along the centerline of the row of absorber tubes (other half is symmetric) with length equal to Word 1 on Card 4CCC0300 and a channel box with length equal to the sum of Words 1 and 2 on Card 4CCC0300. The total mass represented by this component is equal to the mass of an individual blade/box structure multiplied by the value on this card. The range is 1 $\leq$ x.

### A5.5.3 Card 4CCC0200, Radial Dimensions

This card is required for NEW problems and cannot currently be changed for RESTART problems.

W1(I) Number of absorber tubes in a control blade wing. This variable is used only to specify the relative proportions of a control blade wing. The length (wetted perimeter) of a control blade is specified in Word 1 on Card 4CCC0300. The range is 1 ≤ x.

W2(R) Inside diameter of stainless steel absorber tube (m, ft). The range is 0.0 ≤ x ≤ 0.0070 m.

W3(R) Thickness of stainless steel absorber tube wall (m, ft). The range is 0.0 ≤ x ≤ 0.0013 m.

W4(R) Thickness of gap between absorber tube and control blade sheath (m, ft). Specify a thickness of 0.0 to eliminate the additional thermal resistance associated with this gap. The range is 0.0 ≤ x ≤ 0.0003 m.

W5(R) Thickness of stainless steel control blade sheath (m, ft). The range is 0.0 ≤ x ≤ 0.0030 m.

W6(R) Distance between control blade and channel box (m, ft). The range is 0.0 ≤ x ≤ 0.0100 m.

W7(R) Thickness of zircaloy channel box wall (m, ft). The range is 0.0 ≤ x ≤ 0.0050 m.

W8(R) Distance between channel box and first row of fuel rods (m, ft). The range is 0.0 ≤ x ≤ 0.0080 m.

### A5.5.4 Card 4CCC0300, Blade/Box Lengths and View Factors

This card is required for NEW problems and cannot currently be changed for RESTART problems.

W1(R) Length (wetted perimeter) of control blade and channel box segment number 1 (m, ft). The range is 0.0 m ≤ x.

W2(R) Length (wetted perimeter) of channel box segment 2 (m, ft). This is the portion of the channel box not adjacent to a control blade. The range is 0.0 m ≤ x.

W3(R) Geometric view factor from channel box segment 1 to control blade. This factor is based on the area of channel box segment 1. The range is 0.0 ≤ x ≤ 1.0.

W4(R) Geometric view factor from channel box segment 2 to control blade. This factor is based on the area of channel box segment 2. The range is 0.0 ≤ x ≤ 1.0.

### A5.5.5 Card 4CCC0400, Upper and Lower Volume Numbers

This card is required for NEW problems and cannot currently be changed for RESTART problems

W1(I) Volume number of hydraulic volume just above the fuel bundle volumes specified in Word 1 on Cards 4CCC0401 through 4CCC0499.

W2(I) Volume number of hydraulic volume just below the fuel bundle volumes specified in Word 1 on Cards 4CCC0401 through 4CCC0499.

### A5.5.6 Cards 4CCC0401 through 4CCC0499, Volume Connections

These cards are required for NEW problems and cannot currently be changed for RESTART problems. A modified sequential expansion format is used where Words 1 and 2 are incremented by Word 3.

W1(I) Volume number of hydraulic volume connected to fuel bundle side of channel box axial node. This is the first volume number used in the sequential expansion. Each subsequent volume number is generated by adding the increment specified in Word 3.

W2(I) Volume number of hydraulic volume connected to control blade axial node and interstitial side of channel box axial node. This is the first volume number used in the sequential expansion. Each subsequent volume number is generated by adding the increment specified in Word 3.

W3(I) Volume number increment. This increment may be positive, negative, or zero.

W4(I) Axial node number used for the sequential expansion. The node numbers specified on these cards must be in ascending, but not necessarily consecutive, order. The range is $\underline{1} \leq x \leq \underline{N}$, where N is the number of axial nodes specified on Card 40000100.

### A5.5.7 Card 4CCC0500, Initial Oxide Thicknesses

This card is optional for NEW problems and cannot currently be changed for RESTART problems.

W1(R) Initial thickness of $ZrO_2$ layer on fuel bundle side of channel box (m, ft). The thicknesses for the two channel box segments and all axial nodes are identical. The default is 0.0 m and the range is 0.0 m $\leq x \leq$ <u>0.5*W7 on Card 4CCC0200</u>.

W2(R) Initial thickness of $ZrO_2$ layer on interstitial side of channel box (m, ft). The thicknesses for the two channel box segments and all axial nodes are identical. The default is 0.0 m and the range is 0.0 m $\leq x \leq$ <u>0.5*W7 on Card 4CCC0200</u>.

W3(R) Initial thickness of stainless steel oxide layer on control blade surfaces (m, ft). The thicknesses for all axial nodes are identical. The default is 0.0 m and the range is 0.0 m $\leq x \leq$ <u>MIN (W3 on Card 4CCC0200, 0.5*W5 on Card 4CCC0200)</u>.

### A5.5.8 Cards 4CCC0601 through 4CCC0699, Initial Temperatures

This card is required for NEW problems and cannot currently be changed for RESTART problems. A sequential expansion format is used.

W1(R) Initial temperature of control blade (K, $^oF$). The temperatures of the three control blade radial nodes are identical at each axial node. The range is $\underline{300} \leq x \leq \underline{1,505\ K.}$

W2(R) Initial temperature of channel box (K, $^oF$). The temperatures of the two channel box segments are identical at each axial node. The range is $\underline{300} \leq x \leq \underline{1,523}$ K.

W3(I) Axial node number used for the sequential expansion. The node numbers specified on these cards must be in ascending, but not necessarily consecutive, order. The range is $\underline{1} \leq x \leq \underline{N}$, where

N is the number of axial nodes specified on Card 40000100.

### A5.5.9 Cards 4CCC0701 through 4CCC0799, Segment 1 Radial Spreading

These cards are optional for NEW problems and cannot currently be changed for RESTART problems. Specify one card for each component that can receive molten material from channel box segment 1. Omit this card if there are no components that can receive molten material from channel box segment 1.

W1(I) Component number of fuel rod or electrically-heated simulator rod component that can receive molten material from channel box segment 1.

W2(R) Mass fraction of molten material from channel box segment 1 received by component specified in Word 1. The range for individual mass fractions is $\underline{1.0e-6} \leq \underline{x} \leq \underline{1.0}$. The sum of all mass fractions on Cards 4CCC0701 through 4CCC0799 must be unity.

### A5.5.10 Cards 4CCC0801 through 4CCC0899, Segment 2 Radial Spreading

These cards are optional for NEW problems and cannot currently be changed for RESTART problems. Specify one card for each component that can receive molten material from channel box segment 2. Omit this card if there are no components that can receive molten material from channel box segment 2.

W1(I) Component number of fuel rod or electrically-heated simulator rod component that can receive molten material from channel box segment 2.

W2(R) Mass fraction of molten material from channel box segment 2 received by component specified in Word 1. The range for individual mass fractions is $\underline{1.0e-6} \leq \underline{x} \leq \underline{1.0}$. The sum of all mass fractions on Cards 4CCC0801 through 4CCC0899 must be unity.

## A5.6 Shroud Component

The shroud component represents structures such as an insulated shroud around a fuel assembly in a test reactor and the reflector around a reactor core.

### A5.6.1 Card 40CC0000, Component Name

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(A) Component name.

W2(A) Keyword - *shroud.*

### A5.6.2 Card 40CC0100, Number of Shroud Configurations

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(I) Number of shrouds.

### A5.6.3 Card 40CC0200, Shroud Geometry

This card is required for NEW problems and cannot currently be input for RESTART problems. Word 1 is required.

W1(R) Perimeter of inner shroud surface (m, ft). Required input.

### A5.6.4 Card 40CC0300, Indices of Materials

This card is required for NEW problems and cannot currently be input for RESTART problems. A shroud component must have at least three materials (even if all three have the same index), and a maximum number defined by the parameter 'ndmatr' in common block 'scddat'. As transmitted by the INEL the maximum number of materials is ten.

W1... (I) Material index. Material layers beginning with outer layer (radial node 1 is at outer edge of outer layer). Indices from Table A4-2. The default materials are Zr, $ZrO_2$, and Zr.

### A5.6.5 Cards 40CC0301 through 40CC0399, Material Layer Radial Coordinates

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1... (R) Coordinate of outer surface of each material layer (m). Assuming the outer surface of shroud has coordinate of "0.0", enter the remaining coordinates in consecutive order. Each material interface must fall on a mesh point.

### A5.6.6 Card 40CC0400, Upper and Lower Hydrodynamic Volumes

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(I) RELAP5 control volume just above the shroud.

W2(I) RELAP5 control volume just below the shroud.

### A5.6.7 Cards 40CC0401 through 40CC0499, Hydraulic Boundary Conditions

This card defines the RELAP5 control volume which provides the boundary conditions for the component. There are usually two control volumes defined for each axial node. However, for the shroud component only, there is the capability to specify a heat flux boundary condition on the outside of the shroud. This is done by specifying zero (0) for the outer hydrodynamic volume and then including Card 40CC8000. Refer to Cards 40CC8N01 through 40CC8N99, Heat Flux Boundary Condition Specifications for further information. This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(I) RELAP5 control volume number that is in contact with the inner surface of the shroud. This inner surface overlays the maximum radial node number for the shroud.

W2(I) RELAP5 control volume number that is in contact with the outer surface of the shroud. This outer surface overlays radial node number 1. Enter "zero" if adiabatic boundary at the outer surface of shroud (outer surface is at radial node 1).

W3(I) Increment.

W4(I) Axial node number.

### A5.6.8 Cards 40CC0501 through 40CC0599, Radial Mesh Spacing

This card specifies the location of radial mesh points across the component. A heat conduction solution is performed at each radial mesh point. The radial mesh points are defined on a line perpendicular to outer surface of shroud and with the radial coordinates increasing in value in the direction pointing from outer surface to inner surface The radial coordinate of 0.0 is on outer surface of shroud and radial coordinate on inner surface of shroud is equal to wall thickness of shroud.

Error trapping includes checks to ensure that the first radial mesh point is located at 0.0, that the mesh points are in consecutive order, and that there is a mesh point at each material interface. For the first axial node only, all radial nodes must be on one card number, even if it is necessary to use continuation cards. The maximum number of radial nodes is twenty.

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1... (R) Input “0.0”.

WN(R) Distance from outer surface of shroud to radial node N (m).

WN+1(I) Axial node number.

### A5.6.9 Cards 40CC0601 through 40CC0699, Initial Temperature

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(R) Initial temperature at radial node 1(K).

WN(R) Initial temperature at radial node N (K).

WN+1(I) Axial node number. The range is $300 \text{ K} \leq x \leq 2{,}033 \text{ K}$[1]

### A5.6.10 Card 40CC0800, Embedded Flow Channel

This card allows the user to model embedded hydrodynamic flow channels within the SHROUD component. This card is optional for NEW problems, and cannot currently be input for RESTART problems.

W1(I) Number of the interval between radial nodes that contains embedded hydrodynamic flow channels, where internal number 1 is between radial nodes 1 and 2.

1. Upper limit based on the melting point of zircaloy.

### A5.6.11 Card 40CC0801 through 40CC0899, Embedded Flow Channel (Continued)

If Card 40CC0800 is entered then this card is required. If not, then this card is not used.

W1(I) Hydrodynamic volume, linked to embedded flow channel at the lowest axial node.

W2(I) Increment. Number to be added to W1 to form hydrodynamic volumes for each volume above W1.

### A5.6.12 Card 40CC0900, Molten Pool

This card is optional on either NEW or RESTART problems; and if entered, controls the interaction between the shroud component and a molten pool.

W1(I) Molten pool interaction flag; optional flag to determine whether or not shroud interfaces with molten pool. If “0” is entered then no interaction is modeled, if “1” is entered, then interaction is modeled. Default is to model shroud interaction with molten pool.

W2(R) Threshold thickness (m, ft). Threshold thickness of liquefied structural material for breakup of crust of solidified molten pool material at periphery of core. If maximum possible rate of melting of structure at periphery of core due to interaction with molten pool is to be modeled, this word should be 0.0, if minimum, this word should be 1.0.

### A5.6.13 Card 40CC1100, Power Multiplier

This card is optional for NEW and RESTART problems, and specifies the fraction of total core power which is generated in this component.

The approach to specify power is as follows. First, a total core time-dependent power is specified (Section A4.1.9). Then a component power multiplier (this card) is used to determine the fraction of core power deposited in this fraction. The power in a single shroud can then be determined by dividing the component power by the number of shrouds represented by this component. The linear heat generation rate at an individual axial node is determined by multiplying the shroud power by an axial power profile factor (Section A5.6.14 & Section A5.6.15) and dividing by the axial node length. The power density at a specific radial node can then be determined by multiplying the local linear heat generation rate by the radial power factor (Section A5.6.16) and dividing by the cross-sectional area associated with that radial node.

W1(R) Fraction. This is the fraction of the core power in this component.

The range for this power multiplier is $0.0 \leq x \leq 1.0$, and the default is 0.0.

### A5.6.14 Card 40CC13P0, Axial Power Profile Time

In the card number, “P” is axial power profile number (start with Number 1).

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(R) End time for which this axial power profile applies (s).

### A5.6.15 Cards 40CC13P1 through 40CC13P9, Axial Power Profile Data

Card numbering is specified similarly to the previous card, with “P” in the card number indicating the axial power profile number. This information is required for each profile and must be specified for each axial node of the component. This input specifies the fraction of rod power which is deposited at the axial node. The axial power fraction will be normalized over the length of the component.

W1... (R) Axial power factor at axial nodes.

The range is $0.1 \leq x \leq 1.4$, and the default is 1.0.

### A5.6.16 Cards 40CC1401 through 40CC1499, Radial Power Profile

This card is optional for NEW problems and cannot currently be input for RESTART problems. The radial power factor is used to determine the power density at each radial node, based upon the local heat generation rate.

W1(R) Radial power factor.

W2(I) Radial node at which W1(R) applies.

The last radial node that is input must align with the outer radius of the fuel pellet. The range is $x \leq 20$, and the default power factor is 1.0.

### A5.6.17 Card 40CC5000, Shroud Insulation and Failure

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(I) Index of material that has its insulation quality degraded after shroud fails. This index must be one of the indexes on Card 40CC0300.

W2(R) Time at which shroud fails. After the time of shroud failure, both sides of the metallic Zr liner on the inside surface of the shroud are calculated to oxidize. In addition, a multiplier is applied to thermal conductivity of the shroud insulation.

W3(R) Multiplier on thermal conductivity for failed shroud.

### A5.6.18 Cards 40CC8N01 through 40CC8N99, Heat Flux Boundary Condition

These cards are used to specify a table of heat flux as a function of time, to be applied on the outer surface of the shroud, and are read if, and only if, the hydrodynamic volume used for the outer surface boundary condition is specified as zero (0). The ‘100s’ digit, shown as ‘N’ in the card number is used to determine the heat flux profile number for n-th time point, in that the first profile should be entered on Cards 40CC8101 through 40CC8199, and the second on 40CC8201 through 40CC8299, and so forth.

There are two possible formats for this card. In the first, a time is entered as Word 1, and a heat flux is entered as Word 2, with no additional input. In this format the specified heat flux will be applied to all axial nodes of the component. In the second format, a time is entered as Word 1, and a series of heat fluxes are entered as Words 2 through N, where N is the number of axial nodes plus 1. In this format, Word 2 specifies the heat flux to be applied at Node 1, Word 3 specifies that at Node 2, and so forth.

This card is required for NEW problems, and cannot currently be input for RESTART problems.

W1(R) Time (s).

W2(R) Heat flux (W/m$^2$, Btu/s-ft$^2$).

# A5.7 ATR Fuel Element

## A5.7.1 Card 40CC0000, Fuel Element Component

This card is required for NEW problems and may not currently be changed on restart.

W1(A) Component name.

W2(A) Keyword - *atr.*

## A5.7.2 Card 40CC0100, Number and Perimeter of Fuel Element

This card is required for NEW problems and may not currently be changed on RESTART.

W1(A) Number of fuel elements.

W2(R) Average fuel element perimeter (m).

## A5.7.3 Card 40CC0400, Upper and Lower Hydraulic Volumes

This card is required for NEW problems and may not currently be changed on RESTART.

W1(I) RELAP5 volume above the fuel element.

W2(I) RELAP5 volume below the fuel element.

## A5.7.4 Cards 40CC0401 through 40CC0450, Inner Hydraulic Volumes

This card is required for NEW problems and may not currently be changed on RESTART.

W1(I) RELAP5 volume numbers connected to the inner surface.

## A5.7.5 Cards 40CC0451 through 40CC0499, Outer Hydraulic Volumes

This card is required for NEW problems and may not currently be changed on RESTART.

W1(I) RELAP5 volume numbers connected to the outer surface.

### A5.7.6 Cards 40CC0501 through 40CC0599, Radial Mesh Spacing

This card is required for NEW problems and may not currently be changed on RESTART.

W1(R) Radial node spacing (m). Starting from the outer surface. Uses axial self-expansion.

### A5.7.7 Cards 40CC0601 through 40CC0699, Initial Temperature Distribution

This card is required for NEW problems and may not currently be changed on RESTART.

W1(R) Initial temperature (K). For each radial node at present axial node. Uses axial and radial self-expansion. The range is 300 K $\leq$ x $\leq$ 913 K.[1]

### A5.7.8 Cards 40CC0801 through 40CC0899, Material Types

This card is required for NEW problems and may not currently be changed on RESTART.

W1(I) Material index. The first and last index numbers must be 15 or 16. Also, the number of material indexes specified must equal the number of material layers specified on the next card. Must be constant with axial nodes, the numbers are used for consistency.

### A5.7.9 Cards 40CC0901 through 40CC0999, Material Layer Spacing

W1(R) Material layer spacing (m). Starting from outer layer. Must be constant with axial nodes, the numbers are used for consistency.

### A5.7.10 Card 40CC1100, Power Multiplier

This card is optional for NEW and RESTART problems. If not specified the component power is set to zero. One and only one word may be entered when power is specified with either a general table or control variable, and three words are required when the power is specified by reactor kinetics. See Section A4.1.9

W1(R) Fraction. If power is specified with ‘table’ or ‘cntlvar’, this is the fraction of the core power in this component. If power is specified with ‘kinetics’ this is the fraction of the fission power in component ‘CC’.

W2(R) If ‘kinetics’, fraction of fission product decay power in component ‘CC’.

W3(R) If ‘kinetics’, fraction of actinide decay power in component ‘CC’.

The range for all fractions are 0.0 $\leq$ x $\leq$ 1.0

### A5.7.11 Card 40CC13P0, Axial Power Profile Time

P axial power profile number. Start with Number 1. This card is required for NEW problems and

1. Based on the melting point of aluminum.

may not currently be input for RESTART problems.

W1(R) End time (s).

### A5.7.12 Cards 40CC13P1 through 40CC13P9, Axial Power Profile Data

This card is required for NEW problems and may not currently be changed on RESTART. This information is required for each profile.

W1... (R) Axial power factor at axial nodes. P axial power profile number. The range is $0.1 \leq x \leq 1.4$.

### A5.7.13 Cards 40CC1401 through 40CC1499, Radial Power Profile

This card is required for NEW problem and may not currently be input for RESTART problems.

W1(R) Radial power factor.

W2(I) Radial node at pellet surface. The last radial node that is input must align with the outer radius of the fuel pellet. The range is $x \leq 20$.

### A5.7.14 Card 40CC1500, Shutdown Time and Fuel Density

This card is optional for NEW problems and may not currently be input for RESTART problems.

W1(R) Time of shutdown (s). This card is required. Default is 1.0e8.

W2(R) Fraction of fuel theoretical density. This card is required. The range is $0.94 \leq x \leq 0.96$. Default is 0.95.

W3(R) $U^{239}$ production per fission. This word is required only if the power for this component is computed using the decay option.

W4(R) $U^{235}$ enrichment. This word is required only if the power for this component is computed using the decay option.

If the power data option on Card 1000 is 'decay,' then you must input either the 15XX Cards, or the 1600, 17XX, and 18XX Card series.

### A5.7.15 Cards 40CC1601 through 40CC1699, Previous Power History

This card is optional for NEW problems and may not currently be input for RESTART problems. A prior power history can be defined for the decay heat calculation and is required to initialize the fission product inventory (PARAGRASS). The power is assumed to be a series of plateaus, with no interpolation. The last power density in this table is the transient power density until the problem time exceeds the shutdown time. Time in this table is referenced to the start of the operation of the reactor and not to the start of the transient analysis.

W1(R) Power history (W/m$^3$). The range is $40.57 \times 10^6 \frac{\mathrm{W}}{\mathrm{m}^3} \leq x \leq 279.3 \times 10^6 \frac{\mathrm{W}}{\mathrm{m}^3}$.

W2(R) Time (s).

### A5.7.16 Cards 40CC2101 through 40CC2199, Fission Product Masses

This card is required.

W1(R) Initial mass of fission product NN (kg).

W2(I) Axial node for sequential expansion.

# A6. UPPER PLENUM STRUCTURE AND CORE PLATE MODEL

This section describes the input cards that are required when using the upper plenum structure (UPS) model and which also may be used in place of a RELAP5 heat structure to model the core plate below a reactor core. Each UPS input card begins with a card number of the general form 48SSTTNN, where SS represents the user-specified upper plenum structure number, TT represents the card type, and NN represents the card count. Word numbers (W1, W2, etc.) are utilized in the following discussion to promote better understanding of the input requirements, but they are not part of the input data.

UPS input values are specified on six cards (or card sets) that contain information about nodalization, physical dimensions, initial conditions, and hydraulic boundary conditions for each different upper plenum structure. As many as ten upper plenum structures can be used in an input deck; although this limit can be increased by changing the value of parameter NMUPD and recompiling SCDAP/RELAP5-3D©.

The UPS input data can be specified in SI or British units. The "Input Units" parameter (Word 1) on RELAP5 Card 102 designates the system of units for the input cards.

To assist the user, the input variables are compared with a range of typical values. If a range violation is encountered, either a warning message or an error message will be printed in the output file. A warning message allows the calculation to proceed, but an error message causes the calculation to terminate after the completion of input processing. The range for a particular input variable is identified in this section in the following format:

Normal type - Print warning message beginning with "$$$$$$$$"

$\underline{0.0} \le x \le 1.0$

Underline - Print error message beginning with "********"

## A6.1 Card 48SS0000, Axial Levels

This card is required for NEW problems and cannot currently be changed for RESTART problems.

W1(I) Total number of axial levels. The range is $\underline{1} \le x \le \underline{15}$. The upper limit of 15 axial levels can be increased by changing the value of parameter NMUPAX and recompiling SCDAP/RELAP5-3D©.

## A6.2 Cards 48SS0101 through 48SS0199, Mesh Data

These cards are required for NEW problems and cannot currently be changed for RESTART problems. For each axial level NN, there must be one Card 48SS01NN.

W1.. (R) Initial lengths of nodes along conduction path (m, ft). For each axial level, specify one word for each conduction node. The number of words on a card defines the total number of conduction nodes at that axial level. The first word is the initial length of the left (or bottom) node, and the last word is the initial length of the right (or top) node. The range for the total number of conduction nodes at an axial level is $\underline{1} \leq x \leq \underline{6}$. The range of the initial lengths of nodes is $\underline{1.0e\text{-}6\ m} \leq x$. The upper limit of 6 conduction nodes at an axial level can be increased by changing the value of parameter NMUPCN and recompiling SCDAP/RELAP5-3D©.

## A6.3 Cards 48SS0201 through 48SS0299, Surface and Relocation Data

These cards are required for NEW problems and cannot currently be changed for RESTART problems. A sequential expansion format is used.

W1(R) Heat transfer surface area ($m^2$, $ft^2$). The surface areas of the left (or bottom) and right (or top) nodes at an axial level are identical. The range is $\underline{0.0\ m^2} < x$.

W2(I) Flag indicating surface orientation. Specify 0 for a vertical orientation or 1 or 2 for a horizontal orientation. If a horizontal structure is located at an axial level directly below a vertical structure, then a flag of 1 indicates that the horizontal surface blocks downward relocation from only the right surface, and a flag of 2 indicates that the horizontal surface blocks downward relocation from both the left and right surfaces. The range is x = 0, 1, or 2.

W3(R) Height along vertical relocation path (m, ft). The heights of the left and right nodes at an axial level are identical. For a horizontal surface, this height must be specified, but is not used. The range is $\underline{1.0e\text{-}6\ m} \leq x$.

W4(I) Axial level used for sequential expansion. The axial levels specified on these cards must be in ascending, but not necessarily consecutive order. The range is $\underline{1} \leq x \leq \underline{N}$, where N is the total number of axial levels specified on Card 48SS0000.

## A6.4 Card 48SS0300, Initial Oxide Thicknesses

This card is optional for NEW problems and cannot currently be changed for RESTART problems.

W1(R) Initial thickness of left (or bottom) oxide layer (m, ft). The thicknesses for all axial levels are identical. The default is 0.0 m and the range is $0.0\ m \leq x \leq N$ where N is the initial length (or half of the initial length when there is only one node at an axial level) of the smallest right (or top) node specified on Cards 48SS0101 through 48SS0199.

W2(R) Initial thickness of right (or top) oxide layer (m, ft). The thicknesses for all axial levels are identical. The default is 0.0 m and the range is $0.0\ m \leq x \leq N$ where N is the initial length (or half of the initial length when there is only one node at an axial level) of the smallest left (or bottom) node specified on Cards 48SS0101 through 48SS0199.

## A6.5 Cards 48SS0401 through 48SS0499, Initial Temperatures

These cards are required for NEW problems and cannot currently be changed for RESTART problems. For each axial level nn, there must be one Card 48SS04NN.

W1.. (R) Initial temperatures of nodes (K, $^{o}$F). For each axial level, specify one word for each conduction node defined on Cards 48SS0101 through 48SS0199. The first word on a card is the initial temperature of the left (or bottom) node, and the last word is the initial temperature of the right (or top) node. The range is $\underline{300\ K} \leq x \leq \underline{N}$ where N is the melting temperature of the metal.

## A6.6 Cards 48SS0501 through 48SS0599, Hydraulic Boundary Conditions

These cards are required for NEW problems, and cannot currently be changed for RESTART problems. A modified sequential expansion format is used where Words 1 and 2 are incremented by Word 3.

W1(I) Volume number of hydraulic volume adjacent to left (or bottom) node. This is the first volume number used in the sequential expansion. Each subsequent volume number is generated by adding the increment specified in Word 3.

W2(I) Volume number of hydraulic volume adjacent to right (or top) node. This is the first volume number used in the sequential expansion. Each subsequent volume number is generated by adding the increment specified in Word 3.

W3(I) Volume number increment. This increment may be positive, negative, or zero.

W4(I) Axial level used for sequential expansion. The axial levels specified on these cards must be in ascending, but not necessarily consecutive order. The range is $\underline{1} \leq x \leq \underline{N}$, where N is the total number of axial levels specified on Card 48SS0000.

# A7. RADIATION HEAT TRANSFER

SCDAP/RELAP5-3D© has the capability of modeling radiation heat transfer between a group of core components, as described in Volume 1. Each group, called an enclosure, typically consists of a separate hydrodynamic flow channel, and an array of various rods which exchange heat through radiation. If the SCDAP components are modeling a reactor core, then a radiation enclosure is normally defined for a rod bundle in each stack of RELAP5 control volumes that represent the fluid flowing through the reactor core.

## A7.1 Radiation Enclosure Number

The radiation heat transfer input is detected by the presence of the two digits ‘49’ at the beginning of the card. The next two digits, specified as ‘NN’ in the following input description, denote the radiation enclosure number.

### A7.1.1 Card 49NN0000, Enclosure Components

This card is required for NEW problems and cannot currently be input for RESTART problems. The presence of this card triggers radiation heat transfer input processing for the next enclosure.

W1(A) Keyword ‘***bundle***’.

## A7.2 User Specified View Factor and Path Length

Either the 1000 or 2000 series cards are needed, but not both. The 1000 series allows the user to specify radiation view factors and path lengths on input, while the 2000 series causes the view factors and path lengths to be automatically generated. The 1000 series cards must be used if the enclosure includes a BWR blade/box component.

### A7.2.1 Card 49NN1000, Number of Components in Enclosure

This card is optional for NEW problems and cannot currently be input for RESTART problems.

W1.. (I) List of component numbers in the enclosure.

The last component number on this card, if it is a shroud component, is assumed to enclose the radiation heat transfer; this implies that all previous components listed, that are shrouds, will have their outer surfaces exposed to this enclosure, and the last component listed will have it’s inner surface exposed to this enclosure.

### A7.2.2 Cards 49NN1001 through 49NN1099, View Factors

This card is optional for NEW problems and cannot currently be input for RESTART problems.

W1.. (R) View factors.

This input should be considered a square matrix of view factors, where, for example, the third word of the second row is the view factor from the third component specified on Card 49NN1000 to the second component specified on Card 49NN1000.

### A7.2.3 Cards 49NN1101 through 49NN1199, Path Length

This card is optional for NEW problems and cannot currently be input for RESTART problems.

W1.. (R) Radiation path lengths.

Just as in Card 49NN1001, this input should be considered a square matrix of radiation path lengths, where, for example, the third word of the second row is the path length from the third component specified on Card 49NN1000 to the second component specified on Card 49NN1000.

## A7.3 Code Calculated View Factor and Path Length

### A7.3.1 Card 49NN2000, Pitch of Rods

W1(R) Pitch (m). Pitch of rods in enclosure.

W2(I) Component number of shroud enclosing this enclosure. This word is optional, and if omitted then the array of fuel rods are regarded as not being enclosed by a shroud.

### A7.3.2 Cards 49NN2001 through 49NN2099, Enclosure Description

W1.. (I) Matrix of integers identifying the component in each slot of the enclosure. If any of these components has a diameter greater than W1 on Card 49NN2000, then option for code calculation of view factors cannot be selected. Instead the view factors must be defined by the user in the A20.2 block of input.

The maximum size of the array is ndcomp x ndcomp, where ndcomp is a parameter defined at compilation which defines the maximum number of components handled by SCDAP/RELAP5-3D©. This parameter is defined to be 20.

# A8. COUPLE CONTROL CARDS

These cards are input whenever a COUPLE calculation is begun. These cards can be entered on either NEW or RESTART problems. Every COUPLE calculation must begin with a 50000000 card. Card 5M010000 may be entered for each COUPLE mesh 'M'.

## A8.1 Card 50000000 COUPLE Identification

This card is required, whenever a COUPLE mesh is to be input.

W1(A) Keyword. 'couple'

W2(A) Input format. Enter the keyword 'old' for old-style (formatted) input, or 'new' for unformatted, RELAP5 card number style input.

## A8.2 Card 50004000 Heat Transfer on External Surface of Lower Head

This card is optional, and may be entered on either NEW or RESTART problems. If entered this card is used to control ex-vessel heat transfer correlations for the external surface of a lower head submerged in a pool of water.

W1(I) Containment volume. This volume is the number of a hydrodynamic volume representing the containment. Any COUPLE node which has this volume specified as the hydrodynamic volume for convective heat transfer will use the ex-vessel heat transfer correlations.

W2(R) Heat transfer coefficient. The heat transfer coefficient to use for vapor phase heat transfer, when the node is modeled as being uncovered.

W3(I) Correlation flag. Integer flag describing which set of boiling correlations to use. Two sets of correlations are currently available. Set 1 (W3 = 1) is a set of correlations for heat transfer to subcooled fluid. Set 2 (W3 = 2) is a set of correlations for heat transfer to saturated fluid. Note that whichever set of correlations are used, the sink temperature will be either the saturation temperature for the pressure in the volume identified in Word 1, or 10 K below that.

W4(I) Containment level variable. (General table if negative, control variable if positive.) The parameter which specifies the containment liquid level.

## A8.3 Card 50005000 Fuel-Coolant Interaction

This card is optional, and may be entered only for NEW problems. For the general analyses of severe accidents, this card and cards 50006000 through 50009000 are omitted. The card defines parameters used in the calculation of the breakup of jets of molten core material penetrating into a pool of water. The mass flow rate, composition, temperature and timing of the jets of slumping material are defined on Cards 5M200000 through 5M20S301, which are described in Section A22. The FCI model is activated by defining W3 on Card 5M010000 (defined in Section A21.13) to be “1” and W4 on this card to be “2”.

W1(R) Parameter to select either Fuel-Coolant Interaction (FCI) involving melted material slumping through holes in core plate or user-definition of size of particles resulting from FCI; -1 = user-definition of origin of FCI, > 0 = number of holes in core plate through which melted material slumps as a jet.

W2(R) If W1 = -1, then W2 = diameter of particles resulting from FCI (m). If W1 > 0, then W2 = diameter of jets of slumping material at point of origin (m).

W3(R) Interval of time associated with each discrete slumping (s). In the numerical solution, the slumping process is discretized so the number of different particles resulting from breakup is finite rather than unlimited. For example, if the slumping in actuality occurs continuously through a 1 s interval of time, and W3(R) has a value of 0.01, then the slumping is discretized into 100 (1/0.01) individual slumpings distributed through the 1 s of time is which the slumping occurred. For most analyses, 0.01 < W3 < 0.05.

## A8.4 Card 50006000 Further Fuel-Coolant Interaction Parameters

W1(R) Maximum liquid volume fraction for all heat transfer from fuel-coolant interaction being received by vapor phase around the dispersed particles. Recommended input value is 0.0.

W2(R) Elevation of bottom of region in which FCI occurs with respect to elevation of inner surface of lower head at its centerline (m). Normally, W2 = 0.0.

W3(R) If W1 on Card 50005000 is < 0, then W3 = area of cross section of slumping material. In this case, W3 is factor in calculating the initial velocity of particles resulting from FCI along with the mass rate of slumping defined on Card 5M200000 and its associated cards. If W1 on Card 50005000 is > 0, then define W3 to be equal to 0.0.

W4(R) Input the integer 1.

## A8.5 Card 50007000 Further Fuel-Coolant Interaction Parameters

W1(R) Elevation of bottom of stack of RELAP5 control volumes referenced in Card 50008000 with respect to bottom center of inside surface of lower head (m). For most analyses, W1 = 0.0.

## A8.6 Card 50008000 RELAP5 Control Volumes in which FCI May Occur

W1(I) Volume number of bottom most RELAP5 control volume in stack of volumes in which FCI may occur (nine digit number).

W2(I) Volume number of RELAP5 control volume just above W1 in stack of volumes in which FCI may occur (nine digit number).

W3(I) - Wn(I) Continue input in pattern shown by W1 and W2, where n = total number of RELAP5 control volumes in which FCI may occur. Continuation cards are allowed. The first continuation card has the number 500080001. Normally, ten or more RELAP5 control volumes overlay the region in which FCI may occur.

## A8.7 Card 50009000 Elevations of RELAP5 Control Volumes in Which FCI May Occur

W1(R) Elevation of top of bottom most RELAP5 control volume in which FCI may occur with respect to elevation of bottom center of inner surface of lower head (m).

W2(R) Elevation of top of second from bottom RELAP5 control volume in which FCI may occur with respect to elevation of bottom center of inner surface of lower head (m).

W3(I) - Wn(I) Continue input in pattern shown by W1 and W2, where n = total number of RELAP5 control volumes in which FCI may occur. Continuation cards are allowed. The first continuation card has the number 500090001.

## A8.8 Card 5M010000, Modeling Options for Lower Head Debris

This section describes COUPLE control cards which are specific to each COUPLE mesh. Each card number begins with two digits, ‘5’ and ‘M’. As described in the previous section, the ‘5’ denotes that COUPLE input is being presented, and the ‘M’ represents the COUPLE mesh number. One of these cards can be read for each COUPLE mesh “M”, where “M” is between 1 and the allowed maximum number of meshes. The maximum allowed number of meshes is defined by parameter ‘maxcpm’ in common block ‘cpmdat’. The maximum number of allowed meshes is 5.

W1(I) COUPLE flag and input indicator.

0 = Used on a restart run to turn off the COUPLE model for mesh “M”.

-1 = Used on a restart run to replace some of the values on this card for mesh “M”.

1 = Read COUPLE input for mesh “M”.

This option can be used on RESTART to add or change a COUPLE mesh, unless debris is received from core components and core slumping into the mesh has already started.

W2(I) The identification number of the RELAP5 Control Volume modeling the fluid contacted by molten material slumping from the core region to the lower head. If W4 = 1 on this card, then slumping of material to lower head results in water in this control volume being converted to steam due to heat transfer from slumping material. On a restart run, this word may not be changed, but a 0 may be entered as input.

W3(I) Debris source indicator for COUPLE mesh “M”:

-1 = No slumping. Debris material is already present at the start of the application.

0 = Debris received from core components (default).

1 = User-defined slumping.

2 = Depends on components above mesh (non LWRs).

Only 1 mesh may be designated as receiving debris from SCDAP/RELAP5-3D© core components.

W4(I) Flag for breakup of COUPLE debris. For general severe accident analyses, W4(I) = 0 or 1;

0 = Debris may be broken up (default).

1 = Debris is never broken up.

2 = Extent of breakup is calculated by Fuel-Coolant Interaction Model. In this case, W3 = 1, and Cards 5M200000 through 5M20S301 are input, and Cards 50005000 through 50009000 are also input.

W5(I) Input the integer’1’

W6(R) Input 1.0.

W7(I) Index for selecting heat transfer and flow loss model for porous debris in lower head of reactor vessel; 0 = simplified model, 1 = detailed heat transfer model and detailed Tung and Dhir[A-2] flow loss model, 2= detailed heat transfer model and detailed Catton and Chung[A-6] flow loss model. Default value: 2.

W8(I) Index to invoke write to an output file of the calculated transient temperature distribution in the lower head of a reactor vessel. This option is invoked when calculated temperature history for lower head is to be input into a computer code for a detailed structural analysis of the lower head. Temperature distribution written to file every ncount/W8 time steps, where ncount = current number of time steps. Output file name: coupfl. Default value: 0.

W9(R) Time at which molten pool in lower head stratifies into a metallic upper part and an oxidic lower part (s). Default value: $1.x10^{15}$.

W10(I) Index for selecting model for angular distribution in heat flux on inner surface of lower head supporting a molten pool; 1 = mini-ACOPO correlation[A-7], 2 = UCLA correlation[A-8]. Default value: 1. Warning: W10 must not be right of column 80 of this card.

# A9. USER-DEFINED CORE SLUMPING

These cards enable the code user to specify a series of one or more slumpings of core material into a COUPLE mesh. At least one COUPLE mesh, and one SCDAP/RELAP5-3D© core component must be specified. The user should note that the card number provides a significant amount of information to the code. The first digit is always ‘5’ to identify it as COUPLE input. The second digit is ‘M’, the mesh number into which the slump enters. The third and fourth digits are ‘20’ to identify this input as pertaining to user-defined slumping.

## A9.1 Slumping Input

### A9.1.1 Card 5M200000, Definition

The first card specifies a SCDAP/RELAP5-3D© general table which is used as a multiplier on the debris power. The specification of the table number may not be changed on restart, although the table itself may be changed. The same table is applied to all slumps.

W1(I) Table number. Table to define the power decay of the slumps.

### A9.1.2 Card 5M20S100, Duration

This card specifies the duration and power of each period of slumping. The card number uses the integer ‘M’ to specify the mesh into which material is slumped, and the integer ‘S’ to specify the slump number in chronological order, maximum of 25 slumps may be defined.

W1(R) Time at which core slumping begins (s). W1 (S-th slumping) > W2 (S - 1th slump). W1 must be greater than the time at which the analysis starts.

W2(R) Time at which core slumping ends (s).

W3(R) Power multiplier.

The total power in the slump (W) is defined by this factor multiplied by the value from the general table specified on Card 5M200000. The power added to the mesh for each time step is then (W3)*(table number from previous card) * (time step)/(W2 - W1), where W1, W2, and W3 are Words 1, 2, and 3, respectively, from this card.

### A9.1.3 Card 5M20S200, Characteristics

W1(R) Temperature of slumped material (K).

W2(R) Radius of particles of slumped material (m).

W3(R) Porosity of slumped materials.

### A9.1.4 Cards 5M20S301 through 5M20S399, Mass

W1(R) Mass of zircaloy that slumped during period (kg).

W2(R) Mass of metallic uranium (kg).

W3(R) Mass of stainless steel (kg).

W4(R) Mass of silver (kg).

W5(R) Mass of boron carbide (kg).

W6(R) Mass of uranium dioxide (kg).

W7(R) Mass of oxidized zircaloy (kg).

W8(R) Mass of aluminum (kg).

W9(R) Mass of lithium (kg).

W10((R) Mass of cadmium (kg).

# A10. REACTOR VESSEL LOWER HEAD AND SUPPORTED DEBRIS

The input data for the reactor vessel lower head and debris supported by the lower head consists of a series of ordered input blocks or input data sections. Those data blocks that do not apply to a particular job may be omitted without affecting other sections of input. Each data block consists of an initial block header card, several data cards, and a block terminator blank card. No units are built into the program, and the user must be careful to be consistent throughout. The input is not free-form and must be properly positioned within the specified columns (spaces) of 80-character records (cards). Integer and exponential types of input data must be right-hand justified. The required type of input data is indicated by A for alphanumeric, I for integer, and R for real. The columns for each piece of input data are specified by the two numbers to the left of the definition of the piece of input data. The type of input data is indicated by the character in parentheses to the right of the column specifier.

Note that a RELAP deck terminator card (period card) should be input prior to the input described in Section A23.

## A10.1 Title Block

### A10.1.1 Header for Title Block

1-5(A) Block header. Since only the first four characters (columns 1 through 4) are actually checked on each block header card for each section, the rest may be used as a comment card.

Always input the following word: title.

### A10.1.2 Title Card

1-80(A) First title card.

### A10.1.3 Title Card

1-80(A) Second title card. This is a good place to list the unit set employed.

### A10.1.4 Block Terminator

Block terminator (blank card).

## A10.2 Mesh Generation Block

### A10.2.1 Header for Mesh Generation Block

1-8(A) Header for mesh generation block. Always input the following word: automesh.

### A10.2.2 Mesh Generator Control Card

1-5(I) Maximum value of I in mesh. This is the maximum number of nodes in the horizontal direction.

6-10(I) Maximum value of J in mesh. This is the maximum number of nodes in the vertical direction.

11-15(I) Number of material blocks to be assigned. This is the number of different material regions specified on the material block assignment Card(s).

16-20(I) Geometric code.

0 = r-, z-axisymmetric.

1 = x-, y-plane body.

21-30(R) Multiplier. This multiplier operates on dimensions that are input on the line segment card(s) and elsewhere in the input. The multiplier allows the COUPLE input to use inches as the unit for length even though the calculations use meters as the unit for length. (This word) x (value of input number) = (dimension in m).

### A10.2.3 Line Segment Cards

Any reasonable combination of internal and external line segments that represent circular arcs, straight lines, or points in the r-, z- or x-, y-plane can be used to generate a finite element mesh. The line segments are defined by the location of the end points. Circular line segments are defined by one intermediate point, or the center, in addition to the end points. The line segment cards can be input in any order. Any given set of (i, j) pairs can be input only once.

The elements that may be filled by relocated material must be quadrilateral and not triangular in shape. Two of the sides must be perpendicular to the direction in which material is transported into the element.

1-3(I) I-coordinate of 1st point.

4-6(I) J-coordinate of 1st point.

4-14(R) R-coordinate of 1st point.

15-22(R) Z-coordinate of 1st point.

If the line segment type (columns 67 to 71) is 0, then omit the input in columns 23 through 66.

23-25(I) I-coordinate of 2nd point.

26-28(I) J-coordinate of 2nd point.

29-36(R) R-coordinate of 2nd point.

37-44(R) Z-coordinate of 2nd point.

If the line segment type (columns 67 to 71) is 1, then omit the input in columns 45 through 66.

45-47(I) I-coordinate of 3rd point.

48-50(I) J-coordinate of 3rd point.

51-58(R) R-coordinate of 3rd point.

59-66(R) Z-coordinate of 3rd point.

67-71(I) Line segment type of parameter.

0 = Point (input only 1st i, j, r, z).

1 = Straight line (input only 1st and 2nd set of i, j, r, z as end point of line).

3 = Circular arc with midpoint of arc specified (input 1st and 3rd sets of i, j, r, z as end points of arc and 2nd set as midpoint on arc).

4 = Circular arc with center of radius of curvature specified (input 1st and 2nd sets of i, j, r, z as end points of arc and 3rd set of r, z as coordinates of center of radius of curvature).

Straight or curved lines segments in the r-, z-plane must correspond to either a straight line (i- or j-constant along line) or a stepped diagonal segment [ABS(vI)=ABS(vJ)] in that i, j plane. Note on a stepped diagonal segment that i is incremented first and then j.

Repeat the line segment Card until the finite element mesh has been completely defined by the specification of line segments. In general, a finite-element mesh can be completely defined by inputting a line segment Card for each segment of the surface of the mesh.

For modeling gap resistances, input two consecutive values of i or j that have identical coordinates.

### A10.2.4 Mesh Generation Block Terminator

Block terminator (blank card).

# A10.3 Material Block

## A10.3.1 Material Block Assignment

A card is needed for each block specified. Each card assigns a material definition number to a block of elements defined by the i, j coordinates.

1-5(I) Material identification number. The COUPLE model considers up to 15 different materials. The materials and their identification numbers are listed in Table A23-1.

**Table A10-1.** COUPLE material indices.

| Material | ID No. |
|---|---|
| Relocated debris | 1 |
| Stainless steel | 2 |
| Inconel | 3 |
| Carbon steel | 4 |
| Coolant | 5 |
| Null material | 6 |
| MHTGR graphite | 7 |
| MHTGR fuel compact | 8 |
| MHTGR target | 9 |
| MHTGR smeared (homogenized) | 10 |
| User-specified materials | 11-15 |

For user-specified materials, the user supplies constant properties by entering values on the Material Properties and Material Data Cards. For user-specified materials, the code will not model phase change.

Each element defined to have relocated debris is considered to contain coolant until the coolant has been displaced by relocated debris that has slumped into the element. The exception to this is the “no slumping” case (Word 3 = -1 on COUPLE Card 5M010000), in which Material 1 is already present at the start of the problem. If on the fission products card(s) the gap heat transfer is not specified for nodes that are part of null element, then no heat transfer will occur across the null element. Null elements are used to differentiate between two regions with different heat generation rates and to model heat transfer between two materials with a possible gap between them.

6-10(I) Minimum i.

11-15(I) Maximum i.

16-20(I) Minimum j.

21-25(I) Maximum j.

26-35(R) Always input 0.0.

36-45(R) Porosity of material in these elements. If material type is 1 and element is at start of analysis, input 1.

46-50(I) Always input the integer 0.

51-55(I) Always input the integer 0.

56-65(R) Particle diameter (mm).

### A10.3.2 Material Block Terminator

Block terminator (blank card).

## A10.4 Material Block

### A10.4.1 Material Block Header

1-8(A) Block header. Always input the following word: material.

### A10.4.2 Material Data Information

1-5(I) Number of different materials to be defined. Materials that do not exist in the finite element mesh can be defined. In the current version of COUPLE input, if Material 5 is to be used, Materials 1, 2, 3, and 4 need also to be defined.

### A10.4.3 Emissivity

1-10(R) Emissivity. Emissivity for internal radiation in material with ID No. 1. The standard value is 0.8.

### A10.4.4 Material Properties

1-5(I) Material identification number. If material identification number greater than 11 is input, then properties are defined as input on this card (density) and on the Material Data Card, but the materials properties do not change with temperature.

11-20(R) Density of material (kg/m$^3$). If null material (an element used to model gap resistance), then leave these columns blank.

21-52(A) Material title information. For example, if stainless steel material, input “stainless steel.”

### A10.4.5 Material Data

These data are used as default values in case built-in procedures (derivative method in COUPLE) fail to meet specified criteria. If data are not available, low-temperature default data given in the following table should be input. These default values are required. If the input columns are left blank, the code does not automatically set the input variable to the default value. See Table A10-1.

1-10(R) Horizontal thermal conductivity, KR (J/m-s-K). Input 0.0 for null material.

11-20(R) Axial thermal conductivity, KZ (J/m-s-K). Input 0.0 for null material.

21-30(R) Specific heat capacity, CP (J/kg-K). Input 0.0 for null material.

31-80 Blank. Unless material = 7, then input next word.

31-40(R) Fast neutron fluence(n/cm**2).

Repeat the two previous cards until each type of material in the mesh has been defined.

If material = 10, then MHTGR is a smeared core, and insert the next card.

### A10.4.6 MHTGR Material Data

1-10(R) Cross-sectional area of graphite (m**2).

11-20(R) Cross-sectional area of fuel compact (m**2).

21-30(R) Cross-sectional area of target (m**2).

31-40(R) Cross-sectional area of helium coolant channels (m**2).

41-50(R) Fast neutron fluence (n/cm**2).

The cross-sectional areas are in the plane perpendicular to longitudinal axis of the reactor core.

### A10.4.7 Material Block Terminator

Block terminator (blank card).

# A10.5 Time Step Data

## A10.5.1 Time Step Data Block Header

1-4(A) Time step data block header. Always input the following word: step.

## A10.5.2 Temperature Control Card

31-40(R) Initial temperature of finite element mesh (K).

41-50(R) Relaxation parameter in numerical solution. Recommended value is 0.5.

51-60(R) Convergence parameter in numerical solution. Recommended value is 1.0. If gap elements (elements with null material) are being modeled, then the computer run time can be very sensitive to this input value. To avoid excessive run time, it may be necessary to define the convergence parameter to be greater than 1.0, perhaps as large as 5.0.

61-70(R) Inner radius of lower head of vessel. Use the same units as the coordinates on the Line Segment Card. If a spherical lower head is not being modeled, input 0.0.

### *A23.5.3.1 Description of Lower Head of Vessel*

1-10(R) Outer radius of region in finite element mesh that can fill with slumping material. Use the same units as the coordinates on the Line Segment Card. If a spherically shaped lower head is being modeled, input 0.0. If a cylindrically shaped lower head is being modeled or plane coordinates are being used, then this input is used. If plane coordinates are being used, this input specifies the inner radius of pipe being modeled in plane geometry.

11-20(R) Thickness of lower head of vessel or elevation of top surface of structural material supporting debris. Use the same units as the coordinates on the Line Segment Card. If a spherical lower head is not being modeled, then input the distance from the bottom of the finite element mesh to the surface that supports the slumping material.

21-25(I) Spherical lower head modeling flag.

0 = Spherical lower head of vessel is not being modeled.

1 = Spherical lower head of vessel is being modeled.

26-30(I) Maximum number of iterations. Recommended value is 10.

31-40(R) Inner radius of region that can fill in with slumping material. Use the same units as for the Line Segment Card. Omit for the case of spherical lower head. For the case of plane geometry, input 1.0.

41-50(R) Depth (thickness) of plane. Use the same units as for the Line Segment Card. Omit this input for axisymmetric geometry.

51-55(I) Transient configuration of debris slumping flag.

0 = Debris slumping is self-leveling throughout the COUPLE mesh.

1 = Configuration of slumped debris is defined by the user.

If this flag is set, the order in which elements receive slumped debris is defined by the user. The user can divide the elements into layers, which will fill sequentially as the debris slumps. Within each layer the debris is assumed to self-level across all elements in that layer. The user defines the layers of elements by adding cards immediately after this one; one card for each layer. The code limits the inputs to 25 elements per layer for up to 25 layers. The last card in the list should contain a single 0 to indicate the end of the list. Each card that defines a layer must conform to the format as defined below.

56-60 (I) Number of stacks of finite volumes through which liquefied core plate material may flow. Omit this input if flow of liquefied core plate material through porous debris is not to be modeled. Default value = 0. Coefficient name = nstkss.

### *A10.5.2.1 Source of melted material slumping onto debris bed (omit if nstkss = 0 on previous card)*

1-10 (R) Rate of slumping of core plate material onto debris bed ((kg/s)/m$^2$). If rate of slumping of zero is input, then rate of slumping is calculated.

11-20 (R) Start time of core plate slumping (s). If rate of slumping is to be calculated, input 1.0. Coefficient name = tscpss.

21-30 (R) End time of core plate slumping (s). If rate of slumping is to be calculated, then input 0.0. Coefficient name = tecpss.

31-40 (R) Melting temperature of core plate (K). Suggested value = 1730. Coefficient name = tpcpss.

### *A10.5.2.2 Material properties and accuracy of solution (omit card if nstkss = 0)*

1-10 (R) Viscosity of liquefied stainless steel (kg/m.s). Suggested value = 0.0032. Coefficient name = viscss.

11-20 (R) Wetting angle of liquefied stainless steel in contact with debris (degrees). Suggested value = 90. Coefficient name = thtwet.

21-30 (R) Surface tension between liquefied stainless steel and debris (N/m). Suggested value =

0.45. Coefficient name = gamssu.

31-40 (R) Accuracy of solution for bed saturation (unitless). Suggested value = 0.001. Coefficient name = accbst.

#### *A10.5.2.3 Identification of finite elements at top of debris bed (omit if nstkss = 0).*

1-5 (I) Number of a finite element at top of debris bed.

6-10 (I) Number of another finite element at top of debris bed.

11-15 (I) Continue defining in every five columns an identification number of a finite element until every finite element in top row of finite elements has been identified.

#### *A10.5.2.4 User-Defined Layer of the COUPLE Mesh*

1-4(I) Number of elements in this layer.

5-10(I) The element number in this layer. Five spaces for each element, continued on the next card if necessary.

The last card in the list must contain a single 0.

### A10.5.3 Block Terminator

Block terminator (blank card).

## A10.6 Internal Heat Generation Block

### A10.6.1 Internal Heat Generation Block Header

1-10(A) Block header. Always input the following word: generation. The generation block is required input.

### A10.6.2 Number of Materials Without Internal Generation

1-5(I) Number of materials for which internal generation is not possible. If relocated debris is being considered, input the number that is one less than the input in Columns 1 through 5 of the Material Data Information Card. Otherwise, input the same number.

6-10(I) NAF. The number of pairs of lines of mass fractions input.

11-15(I) NFP. The number of lines of fission products input.

### A10.6.3 Power Densities

These cards are optional for the "no slumping" COUPLE case (Word 3 = -1 on the Couple Card 5M0010000), and are not allowed otherwise. Each card defines a power density for a specified group of consecutive nodes. This input can be used for selected nodes to override the power density option set for all COUPLE Material 1 by SCDAP.

1-5(I) I1I of first node in the group.

6-10(I) J1J of first node in the group.

11-15(I) I2I of last node in the group.

16-20(I) J2Jof last node in the group.

21-30(R) X204 Multiplier of power density from Table N402. If N402 = 0, then X204 = constant power density ($W/m^3$).

31-35(I) N402 Number of RELAP5 general tables of power density ($W/m^3$).

### A10.6.4 Block Terminator

Blank card.

## A10.7 Material Without Internal Generation

### A10.7.1 Material Numbers Without Internal Generation

1-5(I) First material number.

6-10(I) Second material number.

Continue in Columns 11-15, 16-20, etc., until all materials defined in the Material Properties Card have been identified. Null material must be defined as material with no internal heat generation.

### A10.7.2 Mass Fractions

These cards are optional for the "no slumping" COUPLE case (Word 3 = -1 on the COUPLE Card 5M001000) and are not allowed otherwise. Each pair of cards defines the mass fractions for the constituents in a consecutive group of COUPLE elements with Material 1. These fractions are converted to atomic fractions and stored as such.

Card 1:

1-5(I) NEL1. Number of first element in the group.

6-10(I) NEL2. Number of last element in the group.

11-20(R) Mass fraction of zircaloy.

21-30(R) Mass fraction of metallic uranium.

31-40(R) Mass fraction of stainless steel.

41-50(R) Mass fraction of silver.

51-60(R) Mass fraction of boron carbide.

61-70(R) Mass fraction of uranium dioxide.

71-80(R) Mass fraction of oxidized zircaloy.

Card 2:

1-10(R) Mass fraction of aluminum.

11-20(R) Mass fraction of lithium.

21-30(R) Mass fraction of cadmium.

31-40(R) Mass fraction of soil.

This input overrides the SCDAP values for the elements specified.

### A10.7.3 Block Terminator

Block terminator (blank card).

## A10.8 Convection Data Block

### A10.8.1 Convection Data Block Header

1-11(A) Block header. Always input the following word: convectsets.

### A10.8.2 Number of Nodes with Convection

1-5(I) Number of nodes in finite element mesh at which convective heat transfer can occur. Nodes that are part of finite elements that receive relocated material should be defined as nodes at which convective heat transfer occurs. Otherwise, convective heat transfer will not be modeled from the surface of particles in porous debris or from the top surface of nonporous debris. Nodes at both surfaces of a gap modeled as null material must be defined. Maximum of 2000 nodes may be defined to have convective heat transfer or be part of gap heat transfer.

6-10(I) Input the integer 1.

### A10.8.3 Boundary Conditions for Elements That Fill With Slumping Debris

1-10(R) Always input 1000.0.

11-20(R) Always input 500.0.

### A10.8.4 Identification of Surfaces With Convective and Radiative Heat Transfer

All convective boundary data should be input for a line of points (that is, i2 equal i1, j2 not equal j1 or i2 not equal i1, j2 equal j1) with the nodal coordinates increasing from the first to the second node. The program will automatically assign values at nodal points intermediate to the first and second defined nodal points. Each line must contain a minimum of two points. Nodes that are on a surface and not listed on the fission product Card are treated as being part of an adiabatic surface.

1-5(I) I coordinate of 1st node.

6-10(I) J coordinate of 1st node.

11-15(I) I coordinate of 2nd node.

16-20(I) J coordinate of 2nd node.

21-30(R) If these convective nodes are not modeling heat transfer across the gap, leave these columns blank. Otherwise, input gap heat transfer coefficient for case of materials in both sides of the gap being solid state.

55-60(I) If these convective nodes are not modeling heat transfer across the gap, leave these columns blank. Otherwise, input -1.

### A10.8.5 Number of Interfacing SCDAP/RELAP5-3D© Volumes

Omit this card if -1 is input in columns 55-60 of the previous card.

1-10(I) Number of SCDAP/RELAP5-3D© volumes that interface with these nodes. Input the full nine-digit number.

The fission product and block terminator cards are repeated as many times as necessary to define all the convection boundary data.

### A10.8.6 Block Terminator

Block terminator (blank card).

## A10.9 Initial Temperature

### A10.9.1 Initial Temperature Block Header

1-8(A) Block header. Always input the following word: tempsets.

### A10.9.2 Number of Temperature Nodes

5-10(I) Number of nodes in mesh at locations that may be filled with slumping debris. Always input the integer 0.

16-20(I) Always input the integer 0.

21-30(R) Always input 0.0.

### A10.9.3 Block Terminator

Block terminator (blank card).

## A10.10 Plot Control

### A10.10.1 Plot Control Header

1-5(A) Block header. Always input the following word: plots.

### A10.10.2 Plot Control Card

1-5(I) Always input the integer 1.

6-10(I) Always input the integer 0.

11-15(I) Always input the integer 2.

### A10.10.3 Plot Control Block Terminator

Block terminator (blank card).

## A10.11 Solution Control

### A10.11.1 Solution Control Header

1-6(A) Block header. Always input the following word: couple.

### A10.11.2 Solution Control Block Terminator

Block terminator (blank card).

### A10.11.3 Problem Termination Card

1-11(A) Problem termination card. Always input the following words: end of data.

Input data for next COUPLE mesh being modeled.

# A11. INPUT FOR MODELING HIGH TEMPERATURE GAS REACTOR

All numerical input for High Temperature Gas Reactor modeling must be input in SI units.

## A11.1 General Input

### A11.1.1 Card 40010000, Specify Modeling of Reactor Core of High Temperature Gas Reactor (HTGR)

W1(A) Eight or less alphanumeric characters used to identify reactor core in output file.

W2(A) htgrcore.

Example input for Card 40010000:

```
*         word(1)   word(2)
40010000  htgrcore  htgrcore
```

### A11.1.2 Card 40010020, Definition of Type of HTGR

W1(I) Identification of type of HTGR (idhtgr); where

1 = pebble bed HTGR.

2 = block-type (prismatic) HTGR.

W2(R) The time for starting calculation of change in stored energy of structural components in the reactor system (timenr in s). Beginning with problem time equal to timenr, variables for auditing the energy balance of the reactor system are calculated. These variables include (1) stored energy changes in the reactor core, reactor vessel, upcomer, downcomer, and containment and any surrounding earth, (2) sum of changes in stored energy of all reactor components, (3) integration with respect to time of fission power, decay heat, and oxidation heat, and (4) sum of heat transferred to air circulating from atmosphere to downcomer annulus, upcomer flow channel, and back to atmosphere. These variables are part of restart-plot file and can be plotted. For analyses beginning with reactor at full power at steady state, the energy audit variables might best be initialized at the time of end of blowdown.

Example input for Card 40010020:

```
*         idhtgr  timenr
40010020  2       0.0
```

## A11.2 Block-type HTGR Input

### A11.2.1 Card 40010022

W1(I) The number of rings of blocks (number of blocks along a radial line extending from center of core to outer edge of core at core mid-plane, numrng).

W2(R) The elevation of bottom of fueled part of core (zbcore in m).

W3(R) The elevation of top of fueled part of core (ztcore in m).

W4(R) The thickness of core barrel (thbar1 in m).

W5(I) The number of radial meshes in core barrel (nmbarl).

W6(R) The emissivity of outer surface of core barrel (embarl).

W7(I) The axial node at bottom of fueled part of core (kcrbot).

W8(R) The porosity of graphite matrix in fuel compacts (pfmtrx).

Example input for Card 40010022:

| * | numrng | zbcore | ztcore | thbarl | nmbarl | embarl | kcrbot | pfmtrx |
|---|---|---|---|---|---|---|---|---|
| 40010022 | 4 | 1.175 | 4.075 | 0.01 | 1 | 0.7 | 11 | 0.05 |

### A11.2.2 Card 40010023, Definition of Block Porosity, Initial Temperature of Reactor Core, and Power History Table

W1(R) The porosity of blocks containing fuel compacts (porosity due to microscopic sized voids in graphite, pblblk).

W2(R) The porosity of reflector blocks (prfblk).

W3(R) The diameter of fuel particles (dfpblk in m). (Variable is not currently used, so a dummy input should be entered).

W4(I) The number of fuel particles per m3 of fuel compact (nfpblk). (Variable is not currently used, so a dummy input should be entered).

W5(I) The number of the RELAP5 table defining history of core average reactor power density (nstcno in W/$m^3$).

W6(R) The initial temperature of reactor core (tihtgr in K). The entire core is initialized to this temperature.

Example input for Card 40010023:

| * | pblblk | prfblk | dfpblk | nfpblk | nstcno | tihtgr |
|---|---|---|---|---|---|---|
| 40010023 | 0.001 | 0.001 | 0.929e-3 | 2.e+8 | 900 | 850. |

### A11.2.3 Card 40010024, Definition of Geometry for First (Center Most) Ring of Blocks in Reactor Core

W1(R) The outer radius of ring (radblk in m).

W2(I) The number of radial meshes for heat conduction in ring (nmsblk). Total number of radial nodes in all rings plus the core barrel must be equal to or less than 24.

W3(R) The flow channel area per unit cross-section area for ring (afrblk in $m^2$).

W4(R) The perimeter in contact with coolant per unit cross-sectional area for ring (prrblk in 1/m).

W5(R) The hydraulic diameter for convective heat transfer for ring (dirblk in m).

W6(R) The gap at outer edge of block (gapblk in m).

W7(R) The cross-sectional area of holes for fuel compacts in block per unit area of block exclusive of coolant channels in block (fulchn).

W8(R) The diameter of holes for fuel channels (dfuchn in m). (Variable is not currently used, so a dummy input should be entered).

Example input for Card 40010024:

```
*         radblk  nmsblk  afrblk  prrblk  dirblk  gapblk  fulchn  dfuchn
40010024  0.619   7       0.0266  10.67   0.01    1.0e-3  0.1578  0.026
```

### A11.2.4 Card 40010025, Definition of Geometry for Second from Center Ring of Blocks in Reactor Core (omit if only one ring of blocks)

W1(R) The outer radius of second ring (radblk in m).

W2(I) The number of radial meshes for heat conduction in ring (nmsblk).

W3(R) The flow channel area per unit cross-section area for ring (afrblk).

W4(R) The perimeter in contact with coolant per unit cross-sectional area for ring (prrblk in 1/m).

W5(R) The hydraulic diameter for convective heat transfer for ring (dirblk in m).

W6(R) The gap at outer edge of block (gapblk in m).

W7(R) The cross-sectional area of holes for fuel compacts in block per unit area of block exclusive of coolant channels in block (fulchn).

W8(R) The diameter of holes for fuel channels (dfuchn in m). (Variable is not currently used, so a dummy input should be entered).

Example input for second from center ring of blocks in reactor core:

```
*         radblk  nmsblk  afrblk  prrblk  dirblk  gapblk  fulchn  dfuchn
40010025  1.03    4       0.0266  10.67   0.01    1.e-3   0.1578  0.026
```

### A11.2.5 Card 40010026, Definition of Geometry for Third from Center Ring of Blocks in Reactor Core (omit if two or less rings of blocks)

W1(R) The outer radius of third ring (radblk in m).

W2(I) The number of radial meshes for heat conduction in ring (nmsblk).

W3(R) The flow channel area per unit cross-section area for ring (afrblk).

W4(R) The perimeter in contact with coolant per unit cross-sectional area for ring (prrblk in 1/m).

W5(R) The hydraulic diameter for convective heat transfer for ring (dirblk in m)

W6(R) The gap at outer edge of block (gapblk in m).

W7(R) The cross-sectional area of holes for fuel compacts in block per unit area of block exclusive of coolant channels in block (fulchn).

W8(R) The diameter of holes for fuel channels (dfuchn in m). (Variable is not currently used, so a dummy input should be entered).

Example input for third ring of blocks:

| * | radblk | nmsblk | afrblk | prrblk | dirblk | gapblk | fulchn | dfuchn |
|---|---|---|---|---|---|---|---|---|
| 40010026 | 1.445 | 4 | 0.0266 | 10.67 | 0.01 | 0.0 | 0.1578 | 0.026 |

### A11.2.6 Card 40010027, Definition of Geometry for Fourth from Center Ring of Blocks in Reactor Core (omit if three or less rings of blocks)

W1(R) The outer radius of fourth ring (radblk in m).

W2(I) The number of radial meshes for heat conduction in ring (nmsblk).

W3(R) The flow channel area per unit cross-section area for ring (afrblk).

W4(R) The perimeter in contact with coolant per unit cross-sectional area for ring (prrblk in 1/m).

W5(R) The hydraulic diameter for convective heat transfer for ring (dirblk in m)

W6(R) The gap at outer edge of block (gapblk in m).

W7(R) The cross-sectional area of holes for fuel compacts in block per unit area of block exclusive of coolant channels in block (fulchn).

W8(R) The diameter of holes for fuel channels (dfuchn in m). (Variable is not currently used, so a dummy input should be entered).

Example input for fourth ring of blocks:

| * | radblk | nmsblk | afrblk | prrblk | dirblk | gapblk | fulchn | dfuchn |
|---|---|---|---|---|---|---|---|---|
| 40010027 | 2.125 | 7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

### A11.2.7 Card 40010028, Definition of Geometry for Fifth from Center Ring of Blocks in Reactor Core (omit if four or less rings of blocks)

W1(R) The outer radius of fifth ring (radblk in m).

W2(I) The number of radial meshes for heat conduction in ring (nmsblk).

W3(R) The flow channel area per unit cross-section area for ring (afrblk).

W4(R) The perimeter in contact with coolant per unit cross-sectional area for ring (prrblk in 1/m).

W5(R) The hydraulic diameter for convective heat transfer for ring (dirblk in m)

W6(R) The gap at outer edge of block (gapblk in m).

W7(R) The cross-sectional area of holes for fuel compacts in block per unit area of block exclusive of coolant channels in block (fulchn).

W8(R) The diameter of holes for fuel channels (dfuchn in m). (Variable is not currently used, so a dummy input should be entered).

### A11.2.8 Card 40010029, Definition of Geometry for Sixth from Center Ring of Blocks in Reactor Core (omit if five or less rings of blocks)

W1(R) The outer radius of sixth ring (radblk in m).

W2(I) The number of radial meshes for heat conduction in ring (nmsblk).

W3(R) The flow channel area per unit cross-section area for ring (afrblk).

W4(R) The perimeter in contact with coolant per unit cross-sectional area for ring (prrblk in 1/m).

W5(R) The hydraulic diameter for convective heat transfer for ring (dirblk in m)

W6(R) The gap at outer edge of block (gapblk in m).

W7(R) The cross-sectional area of holes for fuel compacts in block per unit area of block exclusive of coolant channels in block (fulchn).

W8(R) The diameter of holes for fuel channels (dfuchn in m). (Variable is not currently used, so a dummy input should be entered).

## A11.3 Pebble Bed HTGR Input.

### A11.3.1 Card 40010100, Geometry for Pebbles and Fuel Particles in Pebble Bed HTGR

W1(R) The diameter of fuel pebbles in reactor core (dfhtgr in m).

W2(R) The diameter of reflector pebbles in reactor core (drhtgr in m).

W3(R) The outer radius of inner cylinder of reflector pebbles (roigsr in m).

W4(R) The inner radius of outer cylinder of reflector (riogsr in m).

W5(R) The outer radius of outer cylinder of reflector (roogsr in m).

W6(R) The diameter of kernel of fuel in fuel particles (duogsr in m).

W7(I) The number of fuel particles per fuel pebble (nuogsr).

W8(R) The thickness of coatings on fuel particles (thkgsr in m).

Example input for Card 40010100:

| * | dfhtgr | drhtgr | roigsr | riogsr | roogsr | duogsr | nuogsr | thkgsr |
|---|---|---|---|---|---|---|---|---|
| 40010100 | 0.050 | 0.050 | 0.35 | 1.75 | 3.31 | 0.0005 | 15000. | 0.21e-3 |

### A11.3.2 Card 40010200, Porosity and Other Data for Pebbles and Fuel Particles

W1(R) The thermal conductivity of coatings of fuel particles (cncgsr in W/m-K).

W2(R) The heat capacity of coatings of fuel particles (cpcgsr in J/kg-K).

W3(R) The density of coatings of fuel particles (dncgsr in $kg/m^3$).

W4(R) The initial temperature of reactor core (tihtgr in K).

W5(R) The porosity of graphite matrix in fuel pebbles (popgsr).

W6(R) The porosity of graphite matrix in reflector pebbles (prpgsr).

W7(R) The porosity of graphite matrix in outer reflector (prrgsr).

Example input for Card 40010200:

| * | cncgsr | cpcgsr | dncgsr | tihtgr | popgsr | prpgsr | prrgsr |
|---|---|---|---|---|---|---|---|
| 40010200 | 40.0 | 1500. | 2000. | 1000. | 0.1 | 0.1 | 0.01 |

### A11.3.3 Card 40010300, Radial Nodalization, Power History Table, and Other Data for PB-HTGR

W1(I) The number of radial meshes in fuel region of core (nrcgsr). Total number of radial meshes in fuel region and the inner and outer reflector regions must be equal to or less than 24.

W2(I) The number of radial meshes in inner reflector region (nrigsr).

W3(I) The number of radial meshes in outer reflector of core (nrogsr).

W4(I) The index for selecting thermal conductivity and heat capacity models (nkegsr); where

1 = the No models.

2 = the Tanaka-Chiska model for particles with limited contact with each other and heat capacity is calculated on the basis of user-defined characteristics of core.

W5(I) The index for selecting diffusivity correlation (ndfgsr); where

1 = Bird et al 1960 correlation. (This is the only selection currently activated.)

W6(I) The number of RELAP5 table (nstcno) defining average reactor core power density (in $W/m^3$).

W7(R) The thickness of outer shell of reflector pebbles (tirgsr in m).

W8(R) The thickness of outer shell of fuel pebbles (tfugsr in m).

Example input for Card 40010300:

```
*         nrcgsr  nrigsr  nrogsr  nkegsr  ndfgsr  nstcno  tirgsr  tfugsr
40010300  10      2       6       1       1       900     0.005   0.005
```

## A11.4 RELAP5 Connections for Block-type and Pebble Bed HTGRs.

### A11.4.1 Card 40010390, Definition of general form for connection of reactor core nodes with RELAP5 volumes

W1(I) The index indicating type of input for specifying connections of structure nodes to RELAP5 volumes (ntypin); where

1 = simplified input (case of either one stack of RELAP5 volumes for entire core or one stack of RELAP5 volumes for every radial mesh in core, and the RELAP5 9-digit volume numbers going from one stack to the adjacent stack change by a fixed increment).

2 = user defines the 9-digit number of the RELAP5 volume at bottom of each stack of volumes overlapping the reactor core.

W2(I) The number of reactor core axial nodes per RELAP5 volume (nthnod).

W3(I) The number of stacks of RELAP5 volumes overlapping the reactor core (nrstck). If W1(I) = 1, this parameter is omitted.

Example input for Card 400100390:

```
*         ntypin  nthnod
40010390  1       1
```

### A11.4.2 Card 40010400, Definition of RELAP5 Volumes In Reactor Core

If W1(I) on Card 40010390 equals 2, omit this card and instead input Cards 40010411, 40010412, etc.

W1(I) The 9-digit number identifying the RELAP5 volume connected to bottom axial node of radial node 1 (ivolcn). For any RELAP5 volume containing fuel pebbles or reflector pebbles, the abrupt area change flag must be turned on (kloss calculated for junction) to activate model for calculating flow losses in a porous medium. For example, the CCC1101 card (Junction Control Flags Card) for a pipe component must have the "a" digit in the packed format "efvcahs" set to "1".

W2(I) The index for RELAP5 volume nodalization in radial direction (lsingl); where

0 = each radial mesh in reactor core interfaces with different stack of RELAP5 volumes.

1 = one stack of RELAP5 volumes represents gas across entire diameter of core.

W3(I) The incremental change in the number of the RELAP5 volume going from a given axial node to adjacent axial node above this node (incorv).

W4(I) The incremental change in the number of the RELAP5 volume going from bottom most axial node in core to radially adjacent bottom most axial node in core (incorh). This input is omitted for the case of one stack of RELAP5 volumes overlapping the entire reactor core.

Example input for card 40010400:

| | | | |
|---|---|---|---|
| * | ivolcn | lsingl | incorv |
| 40010400 | 100010000 | 1 | 10000 |

### A11.4.3 Card 40010411, Define Stack of RELAP5 Volumes Interfacing Radial Nodes at Center of Core

This input is for the case of more than one stack of volumes connecting to the entire core (i.e., W1(I) of Card 40010390 =2). Cards 40010411 and 40010412 are omitted if W1(I) on Card 40010390 = 1.

W1(I) RELAP5 volume at center of reactor core at bottom axial node in reactor core (ibotch).

W2(I) The number of reactor core radial node at outer edge of center stack of volumes (nradsk). Radial node 1 is always on the centerline of the reactor core.

W3(I) The incremental change in number of RELAP5 volume going from a given axial node to adjacent axial node for center stack of RELAP5 volumes (incrvl).

Example input for Card 40010411:

| | | | |
|---|---|---|---|
| * | ibotch | nradsk | incrvl |
| 40010411 | 100010000 | 4 | 10000 |

### A11.4.4 Card 40010412, Define Second Stack of RELAP5 Volumes in Reactor Core

W1(I) The RELAP5 volume at the bottom axial node in the reactor core for a stack of volumes adjacent to stack of volumes at center of core (ibotch). (The stack of RELAP5 volumes at center of core is defined as first stack of volumes and the stack of RELAP5 volumes adjacent to this stack is defined as the second stack.)

W2(I) The reactor core radial node number at the outer edge of the second stack of volumes (nradsk). Radial node 1 is always on the centerline of the reactor core

W3(I) The incremental change in RELAP5 volume number going from a given axial node to adjacent axial node for the second stack of RELAP5 volumes (incrvl).

### A11.4.5 Card 40010413, Define Third Stack of RELAP5 Control Volumes in Reactor Core

This input should be omitted if two stacks of RELAP5 volumes overlap the entire core.

W1(I) The RELAP5 volume at bottom axial node in reactor core for stack of volumes adjacent on inner side to second stack of RELAP5 volumes (ibotch).

W2(I) The reactor core radial node number at the outer edge of third stack of volumes (nradsk). Radial node 1 is always on the centerline of the reactor core

W3(I) The incremental change in RELAP5 volume number going from a given axial node to adjacent axial node for third stack of RELAP5 volumes (incrvl).

### A11.4.6 Card 40010414, Define Fourth Stack of RELAP5 Volumes in Reactor Core

This input should be omitted if three or less stacks of volumes overlap the entire core.

W1(I) The RELAP5 volume at bottom axial node in reactor core for stack of volumes adjacent on inner side to third stack of RELAP5 volumes (ibotch).

W2(I) The reactor core radial node number at the outer edge of fourth stack of volumes (nradsk). Radial node 1 is always on the centerline of the reactor core

W3(I) The incremental change in RELAP5 volume number going from a given axial node to adjacent axial node for fourth stack of RELAP5 volumes (incrvl).

### A11.4.7 Card 40010415, Define Fifth Stack of RELAP5 Control Volumes in Reactor Core

This input should be omitted if four or less stacks of volumes overlap the entire core.

W1(I) The RELAP5 volume at bottom axial node in reactor core for stack of volumes adjacent on inner side to fourth stack of RELAP5 volumes (ibotch).

W2(I) The reactor core radial node number at the outer edge of fifth stack of volumes (nradsk). Radial node 1 is always on the centerline of the reactor core

W3(I) The incremental change in RELAP5 volume number going from a given axial node to adjacent axial node for fifth stack of RELAP5 volumes (incrvl).

### A11.4.8 Card 40010416, Define Sixth Stack of RELAP5 Control Volumes in Reactor Core

This input should be omitted if five or less stacks of volumes overlap the entire core.

W1(I) The RELAP5 volume at bottom axial node in reactor core for stack of volumes adjacent on inner side to fifth stack of RELAP5 volumes (ibotch).

W2(I) The reactor core radial node number at the outer edge of sixth stack of volumes (nradsk).

Radial node 1 is always on the centerline of the reactor core

W3(I) The incremental change in RELAP5 volume number going from a given axial node to adjacent axial node for sixth stack of RELAP5 volumes (incrvl).

### A11.4.9 Card 40010422, RELAP5 Volumes Interfacing Outer Surface of Core

W1(I) The 9-digit RELAP5 volume number interfacing outer surface of reactor core at bottom most axial node in reactor core (ibotsr).

W2(I) The incremental change in the RELAP5 volume number going from a given axial node to adjacent axial node above this node for stack of RELAP5 volumes interfacing outer surface of reactor core (inbypi).

W3(I) The number of reactor core axial nodes per RELAP5 volume for outer surface of reactor core (nthbyp).

Example input for Card 40010422:

```
*         ibotsr        inbypi  nthbyp
40010422  300010000     10000   1
```

### A11.4.10 Card 40010450, RELAP5 Volumes Immediately Above and Below Reactor Core

W1(I) The number of RELAP5 volume immediately below reactor core (ir5cbt).

W2(I) The number of RELAP5 volume immediately above reactor core (ir5ctp).

Example input for Card 40010450:

```
*         ir5cbt        ir5ctp
40010450  015010000     180010000
```

## A11.5 Power Profiles

### A11.5.1 Card 40010500, Axial Power Profile in Reactor Core (Axial Power Factors)

W1(R) The ratio of power density at the first elevation defined on Card 40010600 to the axially averaged power density (axial power shape factor) [pwzgsr(1)]. For a given elevation, the axial shape factors are assumed to be the same for each radial node at that elevation.

W2(R) The axial power shape factor at second elevation [pwzgsr(2)].

Continue defining axial power shape factors for each elevation defined on Card 40010600. The axial power factor at any location in the reactor core is calculated by interpolating within the table created by Cards 40010500 and 40010600. Card 40010500 can be extended to two or more lines of input by placing a + in column 1 of second and subsequent lines of input. Axial power profile can be defined at maximum of 100 elevations.

Example input for Card 40010500:

```
*         pwzgsr(1) pwzgsr(2) pwzgsr(3) pwzgsr(4) pwzgsr(5) pwzgsr(6)
```

```
40010500    0.58     0.99     1.43     1.76     1.87     1.84
+           1.71     1.50     1.29     1.04
```

### A11.5.2 Card 40010600, Axial Power Profile in Reactor Core (Elevations)

W1(R) The elevation corresponding with the first axial power shape factor defined on Card 40010500 (zpwgsr(1) in m).

W2(R) The elevation corresponding with the second axial power shape factor defined on Card 40010500 (zpwgsr(2) in m).

Continue defining elevations for each axial power shape factor defined on Card 40010500. The first elevation must correspond with 0.0 (elevation of bottom of reactor core), and the last elevation must be equal to or greater than top elevation of reactor core. The reactor core is defined to include both the fueled and reflector parts of the core. Card 40010600 can be extended to two or more lines of input by placing a + in column 1 of second and subsequent lines of input.

Example input for Card 40010600:

```
*           zpwgsr(1) zpwgsr(2) zpwgsr(3) zpwgsr(4) zpwgsr(5) zpwgsr(6)
40010600    0.0       1.275     2.125     2.975     3.825     4.675
+           5.525     6.375     7.225     8.50
```

### A11.5.3 Card 40010700, Radial Power Profile (Radial Power Profile Factors)

W1(R) The ratio of power density at the first radius defined on Card 40010800 to the radially averaged power density (radial power shape factor) [pwrgsr(1)]. For a given radius, the radial power shape factors are assumed to be the same every axial node at that radius.

W2(R) The ratio of power density at the second radius defined on Card 40010800 to radially averaged power density (radial power shape factor at second radius) [pwrgsr(2)].

Continue defining radial power shape factors for each radius defined on Card 40010800. The radial power factor at any location in the reactor core is calculated by interpolating within the table created by Cards 40010700 and 40010800. Card 40010700 can be extended to two or more lines of input by placing a + in column 1 of second and subsequent lines of input. Radial power shape factors can be defined at maximum of 24 radii.

Example input for Card 40010700:

```
*           pwrgsr(1) pwrgsr(2) pwrgsr(3) pwrgsr(4) pwrgsr(5) pwrgsr(6)
40010700    0.0       0.0       0.75      1.00      0.91      0.83
+           0.83      0.0       0.0
```

### A11.5.4 Card 40010800, Radial Power Profile (Radius of Each Radial Power Profile Factor)

W1(R) The radius corresponding with first radial power shape factor defined on Card 40010700 [rpwgsr(1)].

W2(R) The radius corresponding with second radial power shape factor defined on Card

40010700 [rpwgsr(2)].

Continue defining radii for each radial power shape factor defined on Card 40010700. The first radius must correspond with 0.0 (radius of centerline of reactor core), and the last radius must be equal to or greater than outer radius of reactor core. The reactor core is defined to include both the fueled and reflector parts of the core. Card 40010800 can be extended to two or more lines of input by placing a + in column 1 of second and subsequent lines of input.

Example input for Card 40010800:

```
*         rpwgsr(1) rpwgsr(2) rpwgsr(3) rpwgsr(4) rpwgsr(5) rpwgsr(6)
40010800  0.0       0.349     0.351     0.525     1.225     1.575
+         1.75      1.76      3.31
```

# A11.6 Pebble Bed Properties

## A11.6.1 Card 40010900, Emissivities of Surfaces of Fuel and Reflector Pebbles (omit for block-type HTGR)

W1(R) The emissivity of surface of fuel pebbles (emfgsr).

W2(R) The emissivity of surface of reflector pebbles (erigsr).

W3(R) The emissivity of surface of outer reflector (erogsr).

Example input for Card 40010900:

```
*         emfgsr  erigsr  erogsr
40010900  0.8     0.8     0.8
```

## A11.6.2 Card 40010910, Axial Nodalization of Bottom and Top Reflectors in Pebble Bed HTGR (omit for block-type HTGR)

W1(I) The top axial node in reflector below fueled part of core (krftpb). If 0, bottom reflector is not modeled.

W2(I) The top axial node in fueled part of reactor core (kcrtop). If kcrtop = total number of axial nodes (naz), then top reflector is not modeled.

Example of Card 40010910:

```
*         krftpb  krftpb
40010910  10      80
```

## A11.6.3 Card 40010920, Characteristics of Bottom and Top Reflectors of Pebble Bed HTGR (omit for block-type HTGR)

W1(R) The vertical flow channel area per unit cross-section area of reflector below fueled part of core (afrfbt).

W2(R) The same as afrfbt (W1(R)), but for the reflector above the fueled part of core (afrftp).

W3(R) The perimeter in contact with coolant per unit cross-sectional area for the bottom reflector (prrfbt in 1/m).

W4(R) The same as prrfbt (W3(R)), but for the top reflector (prrftp in 1/m).

W5(R) The thickness of the gaps in radial direction in the bottom reflector (tcrfbt in m). The radial gaps are assumed to be in form of a circle in a horizontal plane. Input 0.0 if no such gaps exist. This value used in calculation of effective thermal conductivity of bottom reflector in radial direction.

W6(R) The same as tcrfbt (W5(R)), but for top reflector (tcrfbt in m).

W7(R) The spacing in the radial direction between radial gaps in bottom reflector (dcrdbt in m). Input 100.0, or any number greater than diameter of core, if no such gaps exist. This value used in calculation of effective thermal conductivity of bottom reflector in radial direction.

W8(R) The same as dcrdbt (W7(R)), but for top reflector (dcrdbt in m).

Example input for Card 40010920:

```
*         afrfbt  afrftp  prrfbt  prrftp  tcrfbt  tcrfbt  dcrdbt  dcrdbt
40010920  0.1     0.1     30.     30.     0.002   0.002   0.35    0.35
```

### A11.6.4 Card 40010930 Porosity, Emissivity, and Coolant Channel Characteristics for Bottom and Top Reflectors of Pebble Bed HTGR (omit for block-type HTGR)

W1(R) The porosity of graphite in bottom reflector (prflbt).

W2(R) The porosity of graphite in top reflector (prfltp).

W3(R) The hydraulic diameter for convective heat transfer, bottom reflector (dirfbt in m).

W4(R) The same as dirfbt (W3(R)), but for top reflector (dirftp in m).

W5(R) The emissivity of internal surfaces in bottom reflector (emrfbt).

W6(R) The emissivity of internal surfaces in top reflector (emrftp).

Example input for Card 40010930:

```
*         prflbt  prfltp  dirfbt  dirftp  emrfbt  emrftp
40010930  0.01    0.01    0.012   0.012   0.8     0.8
```

Card 40010930 is last input card for defining the reactor core of a HTGR.

## A11.7 Reactor Vessel Input

Cards 40020000 through 40020200 should be omitted if reactor vessel is not being modeled.

### A11.7.1 Card 40020000, Specify Modeling of Vessel of HTGR

W1(A) Eight or less alphanumeric characters used to identify reactor vessel in output file.

W2(A) htgrvess

Example input for Card 40020000:

| * | W1(A) | W2(A) |
|---|---|---|
| 40020000 | vessel | htgrvess |

### A11.7.2 Card 40020100, Characteristics of Reactor Vessel

W1(R) The inner radius of reactor vessel (rvigsr in m).

W2(R) The outer radius of reactor vessel (rvogsr in m).

W3(I) The number of radial nodes in reactor vessel (nvsgsr). The number of radial nodes must be equal to or less than 25.

W4(I) The inner radius of second (outer) material in reactor (rvmgsr in m). If vessel composed of one material, input "0.0".

W5(I) The radial node at interface of first (inner) and second (outer) materials in reactor vessel (nvmgsr). If vessel composed of one material, input "0".

W6(I) The index identifying material in inner part of vessel material (imives); where

1 = carbon steel (no other material can currently be defined).

W7(I) The index identifying material in outer part of vessel (imoves); where

1 = insulation with thermal conductivity of 0.161 W/m-K and heat capacity of $0.25x10^5$ J/kg-K. No other material is currently being modeled. Input "0" if second material not being modeled.

W8(R) The initial temperature of vessel (tivgsr in K).

Example input for Card 40020100:

| * | rvigsr | rvogsr | nvsgsr | rvmgsr | nvmgsr | imives | imoves | tivgsr |
|---|---|---|---|---|---|---|---|---|
| 40020100 | 2.75 | 2.85 | 5 | 0.0 | 0 | 1 | 0 | 600. |

### A11.7.3 Card 40020110, Emissivities of Inner and Outer Surfaces of Reactor Vessel

W1(R) The emissivity of inner surface of reactor vessel (evigsr).

W2(R) The emissivity of outer surface of reactor vessel (evogsr).

Example input for card 40020110:

| * | evigsr | evogsr |
|---|---|---|
| 40020110 | 0.8 | 0.8 |

### A11.7.4 Card 40020200, Interface of RELAP5 Volumes with Reactor Vessel

W1(I) The 9-digit number identifying the RELAP5 volume connected to bottom axial node of inner surface of reactor vessel (ivlvsi).

W2(I) The 9-digit number identifying RELAP5 volume connected to bottom axial node of outer surface of reactor vessel (ivlvso).

W3(I) The incremental change in number of RELAP5 volume going from a given axial node to adjacent axial node above this node for inner surface of vessel (invesi).

W4(I) The incremental change in number of RELAP5 volume going from a given axial node to adjacent axial node above this node for outer surface of vessel (inveso).

W5(I) The number of axial nodes in structure per RELAP5 volume for inner surface of vessel (nthndi).

W6(I) The number of axial nodes in structure per RELAP5 volume for outer surface of vessel (nthndo).

Example input for Card 40020200:

| * | ivlvsi | ivlvso | invesi | inveso | nthndi | nthndo |
|---|---|---|---|---|---|---|
| 40020200 | 300010000 | 500010000 | 10000 | 10000 | 1 | 1 |

Card 40020200 is last input card for reactor vessel.

## A11.8 Upcomer/Downcomer Input

Cards 40030000 through 40030200 define modeling of the upcomer and downcomer for removal of long-term decay heat by natural circulation of atmospheric air. If the reactor system contains no upcomer or downcomer, Cards 40030000 through 40030200 are omitted. The upcomer is the structure defining the flow path for the upward flow part of the natural circulation loop. This flow path is assumed to be closer to the reactor vessel than the downward flow path. The shape of the horizontal cross section of the flow path for the upcomer can be either an annulus or a series of rectangular cross sections arranged on a circle.

### A11.8.1 Card 40030000, Specify Modeling of Upcomer

W1(A) Eight or less alphanumeric characters used to identify the upcomer in output file.

W2(A) htgrairc

Example input for Card 40030000:

| * | W1(A) | W2(A) |
|---|---|---|
| 40030000 | upcomer | htgrairc |

### A11.8.2 Card 40030100, General Characteristics of Upcomer.

W1(R) The inner radius of upcomer (ridgsr in m).

W2(R) The thickness in radial direction of structure defining flow path for upward flow of air in natural circulation loop connected to atmosphere (tawgsr in m). For annulus cross section of flow path, tawgsr is difference between radii of outer and inner surfaces of upcomer. For upcomer consisting of a series of separated air flow channels arranged in a circle, tawgsr is difference between radii of outer and inner surfaces of these structures defining the air flow paths.

W3(I) The total number of radial nodes used in modeling heat conduction in upcomer (nacgsr, where nacgsr is limited to a maximum of 24).

W4(R) The initial temperature of upcomer (tidgsr in K).

W5(R) The emissivity of exterior surface of upcomer (emsdwn).

W6(I) The index identifying material composition of upcomer (imtlac); where

1 = stainless steel (which is the only material currently allowed).

W7(I) The index for indicating whether upcomer has annulus cross section or consists of a series of separated air flow channels arranged in a circle (inflow); where

0 = annulus cross section,

1 = series of separated air flow channels arranged in a circle.

Example input for Card 40030100:

| * | ridgsr | tawgsr | nacgsr | tidgsr | emsdwn | imatlc | inflow |
|---|---|---|---|---|---|---|---|
| 40030100 | 6.0 | 0.254 | 8 | 400.0 | 0.9 | 1 | 1 |

### A11.8.3 Card 40030120, Geometrical Parameters of Upcomer Composed of Series of Separated Flow Channels for Air (omit if inflow = 0 on Card 40030100)

W1(R) The outer width (circumferential direction) of an individual channel for air flow at mid-radius of channel (wbdgsr in m).

W2(R) The width (circumferential direction) at mid-radius of gap between the individual channels for air flow (wgdgsr in m).

W3(R) The width (circumferential direction) at mid-radius of internal flow area inside individual channel for air flow (wfdgsr in m).

W4(R) The thickness of inner wall (wall facing reactor vessel) of air flow channels (taigsr in m).

W5(R) The thickness of outer wall (wall facing downcomer) of air flow channels (taogsr in m).

W6(I) The radial node at outer surface of inner wall of air flow channels (nr12ac).

W7(I) The radial node at inner surface of outer wall of air flow channels (nr23ac).

Example input for Card 4003120:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| * | wbdgsr | wgdgsr | wfdgsr | taigsr | taogsr | nr12ac | nr23ac |
| 40030120 | 5.08e-2 | 5.08e-2 | 3.81e-2 | 6.35e-3 | 6.35e-3 | 3 | 6 |

### A11.8.4 Card 40030200, Interface of RELAP5 Volumes with Upcomer

W1(I) The 9-digit number identifying RELAP5 volume connected to bottom axial node of inner surface of upcomer (ivlvsi).

W2(I) The 9-digit number identifying RELAP5 volume connected to bottom axial node of outer surface of upcomer (ivlvso).

W3(I) The incremental change in number of RELAP5 volume going from a given axial node to adjacent axial node above this node for inner surface of upcomer (invesi).

W4(I) The incremental change in number of RELAP5 volume going from a given axial node to adjacent axial node above this node for outer surface of upcomer (inveso).

W5(I) The number of axial nodes in structure per RELAP5 volume for inner surface of upcomer (nthndi).

W6(I) The number of axial nodes in structure per RELAP5 volume for outer surface of upcomer (nthndo).

W7(I) The 9-digit number identifying RELAP5 volume connected to bottom axial node for flow area inside upcomer (ibotac). Omit if inflow = 0 on Card 40030100.

W8(I) The incremental change in number of RELAP5 volume going from a given axial node to adjacent axial node above this node for flow area inside upcomer (incrac). Omit if inflow = 0 on Card 40030100.

W9(I) The number of structural axial nodes per RELAP5 volumes representing flow inside upcomer (nthnod). Omit if inflow = 0 on Card 40030100.

Example input for card 40030200:

| | | | | | | |
|---|---|---|---|---|---|---|
| * | ivlvsi | | ivlvso | | | |
| 40030200 | 500010000 | | 500010000 | | | |
| * | invesi | nthdni | nthdno | ibotac | incrac | nthnod |
| + | 10000 | 1 | 1 | 600010000 | 10000 | 1 |

### A11.8.5 Card 40040000, Downcomer Input

W1(A) Eight or less alphanumeric characters used to identify downcomer in output file.

W2(A) htgrdncm

Example input for Card 40040000:

| | | |
|---|---|---|
| * | W1(A) | W2(A) |
| 40040000 | downcomr | htgrdncm |

### A11.8.6 Card 40040100, General Characteristics of Downcomer.

W1(R) The inner radius of downcomer (ribgsr in m).

W2(R) The difference between radii of outer and inner surfaces of downcomer (thkdwn in m).

W3(I) The number of radial nodes in downcomer (ndngsr, where ndngsr is limited to a maximum of 24).

W4(I) The index identifying material composition of the downcomer (imtldn); where

1 = stainless steel (which is the only material currently allowed).

W5(R) The initial temperature of downcomer (tibgsr in K).

W6(R) The emissivity of surfaces of downcomer (emscav).

Example input for Card 40040100:

```
*         ribgsr   thkdwn  ndngsr  imtldn  tibgsr  emscav
40040100  8.0      2.5e-2  5       1       350.0   0.8
```

### A11.8.7 Card 40040200, Interface of RELAP5 Volumes with Downcomer

W1(I) The 9-digit number identifying RELAP5 volume connected to bottom axial node of inner surface of downcomer (ivlvsi).

W2(I) The 9-digit number identifying RELAP5 volume connected to bottom axial node of outer surface of downcomer (ivlvso).

W3(I) The incremental change in number of RELAP5 volume going from a given axial node to adjacent axial node above this node for inner surface of downcomer (invesi).

W4(I) The incremental change in number of RELAP5 volume going from a given axial node to adjacent axial node above this node for outer surface of downcomer (inveso).

W5(I) The number of axial nodes in structure per RELAP5 volume for inner surface of downcomer (nthndi).

W6(I) The number of axial nodes in structure per RELAP5 volume for outer surface of downcomer (nthndo).

Example input for Card 40040200:

```
*         ivlvsi     ivlvso     invesi  inveso  nthndi  nthndo
40040200  500010000  700010000  10000   10000   1       1
```

## A11.9 Reactor Containment

Cards 40050000 through 40050200 define modeling of reactor containment and surrounding material. These cards are omitted if containment and surrounding material are not being modeled. The modeling of the reactor containment requires the modeling of reactor vessel. If the rector design does not include an upcomer and downcomer, then the cards for containment input are 4003xxxx cards instead of 4005xxxx cards.

### A11.9.1 Card 40050000, Specify Modeling of Reactor Containment and Surrounding Material

W1(A) Eight or less alphanumeric characters used to identify reactor containment in output file.

W2(A) htgrcont

Example input for Card 40050000:

```
*         W1(A)      W2(A)
40050000  conearth   htgrcont
```

### A11.9.2 Card 40050100, Characteristics of Containment and Surrounding Material

W1(R) The inner radius of containment (rcigsr in m).

W2(R) The outer radius of containment and if present, surrounding earth in contact with the containment, (rcogsr in m). If containment in contact with surrounding earth, set rcogsr to upper bound of radius that heat from reactor may be transported.

W3(I) The number of radial nodes in containment and any surrounding material (ncngsr). The number of radial nodes must be equal to or less than 24.

W4(R) The thickness of liner on concrete at inside surface of containment (thklnr in m). If containment designed to not have liner, input "0.0".

W5(I) The radial node at interface of liner and concrete for case of containment composed of liner, concrete, and earth; radial node at interface of concrete and containment for case of containment composed of concrete and surrounding earth (ncmgsr). If containment does not have liner and is not in contact with surrounding earth, input "0".

W6(I) The index identifying material in liner of containment (imicon); where

1 = containment has liner composed of stainless steel (which is the only material currently allowed). If containment does not have a liner, input "0".

W7(I) The index identifying material composition of containment (imocon); where

1 = concrete (which is the only material currently allowed).

W8(R) The initial temperature of containment (ticgsr in K).

Example input for Card 40050100:

```
*         rcigsr  rcogsr  ncngsr  thklnr  ncmgsr imicon imocon ticgsr
40050100  10.0    14.0    12      2.5e-2  2      1      0      300.
```

### A11.9.3 Card 40050110, Additional Characteristics of Containment

W1(R) The thickness of concrete wall of containment (thkcon in m).

W2(I) The radial node at interface of concrete and earth (nc3gsr). If earth not in contact with containment, input "0".

W3(R) The emissivity of inner surface of containment (ecngsr).

Example input for Card 40050110:

| | | | |
|---|---|---|---|
| * | thkcon | nc3gsr | ecngsr |
| 40050110 | 1.0 | 6 | 0.7 |

### A11.9.4 Card 40050200, Interface of RELAP5 Volumes With Inner Surface of Containment

W1(I) The 9-digit number identifying RELAP5 volume connected to bottom axial node of inner surface of containment (ivlcon).

W2(I) The incremental change in number of RELAP5 volume going from a given axial node to adjacent axial node above this node (incont).

W3(R) The number of structure axial nodes per RELAP5 volume (nthnod).

Example of input for Card 40050200:

| | | | |
|---|---|---|---|
| * | ivlcon | incont | nthnod |
| 40050200 | 700010000 | -10000 | 1 |

# A12. REFERENCES

A-1. The RELAP5-3D Code Development Team, *RELAP5-3D© Code Manual*s, INEEL-EXT-98-00834, May 2002.

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